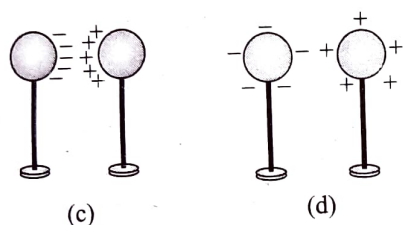
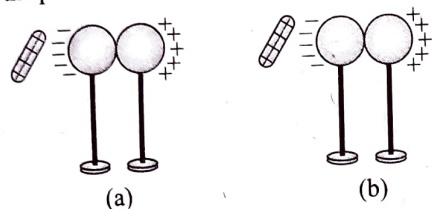


CHAPTER 1

DPP 1.1

Subjective Type

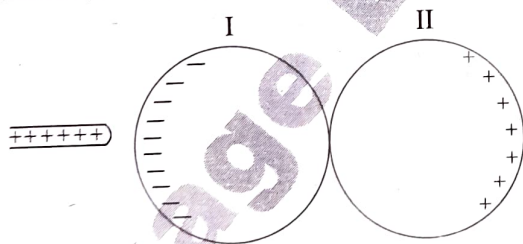
1. (i) When the spheres are slightly separated, they retain their charges at the previous positions as shown in Figure (b).
 (ii) On removal of the glass rod, the charges on the spheres move to the positions facing each other as shown in Figure (c).



- (iii) When the spheres are separated far apart, the charges are uniformly distributed on their surfaces as shown in Figure (d).

Single Correct Answer Type

2. (c) The positively charged insulator pulls the free electron in spheres towards left till electrostatic equilibrium is reached. Hence if both spheres are now separated, Sphere II has deficiency of electrons, i.e., it has positive charge.



3. (c) Let us consider ball 1 has any type of charge. Balls 1 and 2 must have different charges, and balls 2 and 4 must have different charges, i.e., balls 1 and 4 must have same charges but electrostatics attraction is also present in (1, 4) which is impossible.
 4. (c) Because in case of metallic sphere either solid or hollow, the charge will reside on the surface of the sphere. Since both spheres have same surface area, so they can hold equal maximum charge.
 5. (b) When a positively charged body is connected to the earth, electrons flow from earth to body and body becomes neutral.
 6. (d) The question is based on the factual statement "True test of electrification is repulsion".

As mentioned in the question, a positively charged rod attracts a non-conducting object, so the two possibilities about the object are whether it is negatively charged or neutral in nature. If it is neutral, then it would be attracted by some other negatively charged body and won't be attracted or repelled by neutral body [for option (a)]. If it is negatively charged, then it would be repelled by negatively charged object and will attract neutral objects. [For options (b) and (c)]

7. (a) When a point positive charge is brought near to an isolated conducting plane, some negative charge develops on the surface of the plane towards the charge and an equal positive charge develops on opposite side of the plane. This process is called charging by induction.
 8. (c) In Case I when both are positively charged, due to induction positive charge moves outwards on spheres, increasing effective distance between the center of charge causing magnitude of the force to decrease.
 9. (a) It can be seen from the diagram that only the sphere B and sphere C repel. Hence they both must be of the same type. According to the fact when at least two spheres are positively charged, both spheres should be positively charged. Since attraction occurs for two remaining pairs, it can be concluded that the sphere A is negatively charged.
 10. (c) As the electron comes near the throat, positive charges are induced on the throat. The induced charges attract the electron and velocity increases. So $V_1 > V_0$.

Multiple Correct Answers Type

11. (a, b, d)

For (a): As the charge is not having any direction associated with it, i.e., being a scalar, it is additive in nature.
 Option (b) is a standard factual statement for charge, but many other physical quantities like KE and mass are not invariant.
 Options (c) and (d): Conservation of physical quantity refers to invariance with time in a given frame of reference, which is not at all concluded from scalar nature of the physical quantity.

12. (b, c)

Suppose a +vely charged sphere is brought near an unchanged metallic sphere; then on nearer surface of the unchanged sphere, negative charge is induced and on farther surface, positive charge is induced. Hence, a force of attraction will be observed between these two spheres. Therefore, if a force of attraction is observed between a +vely charged sphere and a metallic sphere, it cannot be concluded that the metallic sphere is necessarily negatively charged. Therefore, (a) is wrong, (b) and (c) are correct.

Comprehension Type

13. (c) For 30 C charge, angle $\in (5^\circ, 9^\circ) \Rightarrow 7^\circ$
 14. (c) In (iii) most of positive charge will run away to the metal knob. So due to less charge on the leaves, the leaves will come closer than before.

DPP 1.2

Subjective Type

1. The fact that the spheres are identical allows us to conclude that when two spheres are in contact, they share equal charge. Therefore, when a charged sphere (q) touches an uncharged one, they will (fairly quickly) each attain half of that charge $q/2$. We start with spheres 1 and 2, each having charge q and experiencing a mutual repulsive force $F = kq^2/r^2$. When the neutral sphere 3 touches sphere 1, the charge of sphere 1 decreases to $q/2$. Then sphere 3 (now carrying charge $q/2$) is brought into contact with

sphere 2. A total amount of $\left(\frac{q}{2} + q\right) = \frac{3}{2}q$ are shared equally between them. Therefore, the charge of sphere 3 is $3q/4$ in the final situation. The repulsive force between spheres 1 and 2 is finally

$$F' = k \frac{(q/2)(3q/4)}{r^2} = \frac{3}{8} k \frac{q^2}{r^2} = \frac{3}{8} F$$

$$\Rightarrow \frac{F'}{F} = \frac{3}{8} = 0.375$$

2. (a) According to the graph, when q_3 is very close to q_1 (at which point we can consider the force exerted by particle 1 on 3 to dominate), there is a (large) force in the positive x -direction. This is a repulsive force, then we conclude q_1 has the same sign as q_3 . Thus, q_3 is a positive-valued charge.
- (b) Since the graph crosses zero and particle 3 is between the others, q_1 must have the same sign as q_2 , which means it is also positive valued. We note that it crosses zero at $r = 0.020$ m (which is a distance $d = 0.060$ m from q_2). Using Coulomb's law at that point, we have

$$\frac{1}{4\pi\epsilon_0} \frac{q_1 q_3}{r^2} = \frac{1}{4\pi\epsilon_0} \frac{q_3 q_2}{d^2}$$

$$\Rightarrow q_2 = \left(\frac{d}{r}\right)^2 q_1 = \left(\frac{0.060 \text{ m}}{0.020 \text{ m}}\right)^2 q_1 = 9.0 q_1,$$

$$\text{or } \frac{q_2}{q_1} = 9.0$$

3. We note that the problem is examining the force on charge A, so that the respective distances (involved in the Coulomb force expressions) between B and A and between C and A do not change as particle B is moved along its circular path. We focus on the endpoints ($\theta = 0^\circ$ and 180°) of each graph, since they represent cases where the forces (on A) due to B and C are either parallel or anti-parallel (yielding maximum or minimum force magnitudes, respectively). We note, too, that since Coulomb's law is inversely proportional to r^2 , then (if, say, the charges were all the same) the force due to C would be one-fourth as big as that due to B (since C is twice as far away from A). The charges, it turns out, are not the same, so there is also a factor of the charge ratio n (the charge of C divided by the charge of B), as well as the aforementioned $\frac{1}{4}$ factor. That is, the force exerted by C is, by Coulomb's law, equal to $\pm \frac{1}{4}n$ multiplied by the force exerted by B.

- (a) The maximum force is $2F_0$ and occurs when $\theta = 180^\circ$ (B is to the left of A, while C is to the right of A). We choose the minus sign and write

$$2F_0 = (1 - \frac{1}{4}n)F_0 \Rightarrow n = -4$$

One way to think of the minus sign choice is $\cos(180^\circ) = -1$. This is certainly consistent with the minimum force ratio (zero) at $\theta = 0^\circ$ since that would also imply

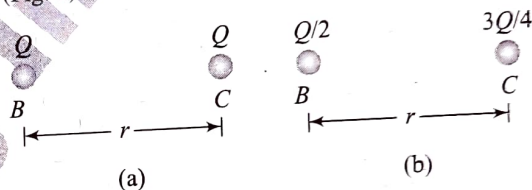
$$0 = 1 + \frac{1}{4}n \Rightarrow n = -4$$

- (b) The ratio of maximum to minimum forces is $1.25/0.75 = 5/3$ in this case, which implies

$$\frac{5}{3} = \frac{1 + \frac{1}{4}n}{1 - \frac{1}{4}n} \Rightarrow n = 16.$$

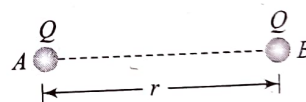
Single Correct Answer Type

4. (d) Initially $F = k \frac{Q^2}{r^2}$ (Fig. a). Finally when a third spherical conductor comes in contact alternately with B and C, then removed, so charges on B and C are $Q/2$ and $3Q/4$ respectively (Fig. b)



$$\text{Now force } F' = k \cdot \left(\frac{Q}{2}\right)\left(\frac{3Q}{4}\right) \frac{1}{r^2} = \frac{3}{8} F$$

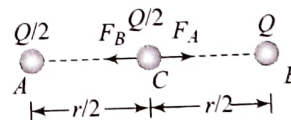
5. (a) Initially



$$F = k \frac{Q^2}{r^2}$$

(i)

Finally



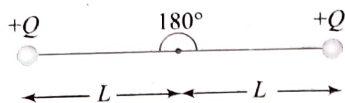
$$\text{Force on C due to A, } F_A = \frac{k(Q/2)^2}{(r/2)^2} = \frac{kQ^2}{r^2}$$

$$\text{Force on C due to B, } F_B = \frac{kQ(Q/2)}{(r/2)^2} = \frac{2kQ^2}{r^2}$$

$$\therefore \text{Net force on C, } F_{\text{net}} = F_B - F_A = \frac{kQ^2}{r^2} = F$$

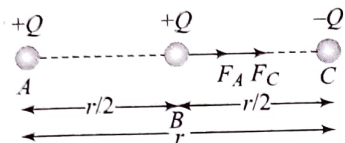
S.4 Electrostatics and Current Electricity

6. (a) In case to weightlessness following situation arises



So angle $\theta = 180^\circ$ and force $F = \frac{1}{4\pi\epsilon_0} \cdot \frac{Q^2}{(2L)^2}$

7. (c) Initially, force between A and C, $F = \frac{kQ^2}{r^2}$

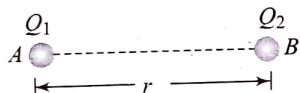


When a similar sphere B having charge $+Q$ is kept at the mid-point of the line joining A and C, then net force on B is

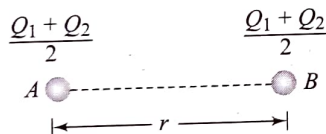
$$F_{\text{net}} = F_A + F_C = k \frac{Q^2}{(r/2)^2} + \frac{kQ^2}{(r/2)^2} = 8 \frac{kQ^2}{r^2} = 8F$$

(Direction is shown in figure)

8. (c) Force on each charge is zero. But if any of the charge is displaced, the net force starts acting on all of them.
9. (a) Suppose the balls have charges Q_1 and Q_2 respectively. Initially,



Finally,



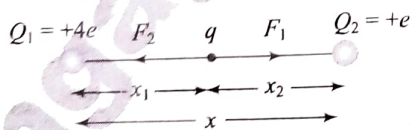
$$F' = \frac{k \left(\frac{Q_1 + Q_2}{2} \right)^2}{\left(\frac{r}{2} \right)^2} = \frac{k(Q_1 + Q_2)^2}{r^2}$$

It is given that $F = 4.5F$ so $\frac{k(Q_1 + Q_2)^2}{r^2} = 4.5k \cdot \frac{Q_1 Q_2}{r^2}$

$$\Rightarrow (Q_1 + Q_2)^2 = 4.5Q_1 Q_2. \text{ On solving it gives } \frac{Q_1}{Q_2} = \frac{2}{1}$$

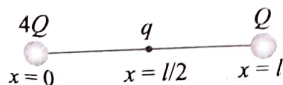
10. (c) For equilibrium of q

$$|F_1| = |F_2|$$



$$\text{Which gives } x_2 = \frac{x}{\sqrt{\frac{Q_1}{Q_2} + 1}} = \frac{x}{\sqrt{\frac{4e}{e} + 1}} = \frac{x}{3}$$

11. (d) The total force on Q



$$\frac{Qq}{4\pi\epsilon_0 \left(\frac{l}{2} \right)^2} + \frac{4Q^2}{4\pi\epsilon_0 l^2} = 0$$

$$\frac{Qq}{4\pi\epsilon_0 \left(\frac{l}{4} \right)^2} = -\frac{4Q^2}{4\pi\epsilon_0 l^2} \Rightarrow q = -Q$$

12. (d) By symmetry of problem the components of force on Q due to charges at A and B along y-axis will cancel each other while along x-axis will add up and will be along CO. Under the action of this force charge Q will move towards O. If at any time charge Q is at a distance x from O.

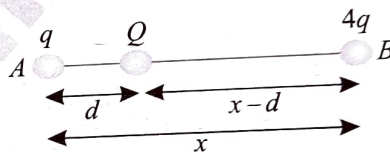
$$F \Rightarrow 2F \cos \theta = 2 \frac{1}{4\pi\epsilon_0} \frac{-qQ}{(a^2 + x^2)} \times \frac{x}{(a^2 + x^2)^{1/2}}$$

$$\Rightarrow F = -\frac{1}{4\pi\epsilon_0} \frac{2qQx}{(a^2 + x^2)^{3/2}}$$

As the restoring force F is not linear, motion will be oscillatory (with amplitude $2a$) but not simple harmonic.

Multiple Correct Answers Type

13. (a, c)



For equilibrium of all the charges net force on each charge should be zero.

$$\frac{KqQ}{d^2} - \frac{4KqQ}{(x-d)^2} = 0 \text{ (Net force on } Q)$$

$$\Rightarrow d = x/3$$

$$\text{and } \frac{KqQ}{d^2} + \frac{4Kq^2}{x^2} = 0 \text{ (Net force on A)}$$

$$\Rightarrow Q = -\frac{4}{9}q \text{ and } d = \frac{x}{3}$$

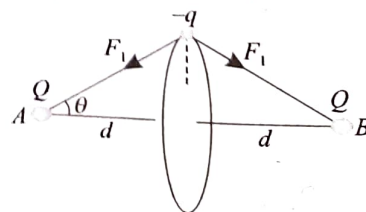
14. (a, c, d)

If charges are equal or unequal, the repulsion force will be the same in magnitude for both the spheres. If weight of both balls are the same, so both will deflect equally. But if the masses of sphere are not equal, the sphere of greater mass will deflect less.

DPP 1.3

Subjective Type

1. Net force on $-q$ towards the centre,



$$F = (2F_1 \cdot \sin \theta) = 2 \cdot \frac{KQ \cdot q}{d^2 + d^2} \times \frac{R}{\sqrt{d^2 + d^2}}$$

For particle to move in circle, $F = m\omega^2 R$

$$\Rightarrow \frac{2KQqR}{(d^2 + R^2)^{3/2}} = m\omega^2 R$$

$$\Rightarrow \omega = \sqrt{\frac{2KQq}{m(d^2 + R^2)^{3/2}}} = 400 \text{ rad/s}$$

2. The net electrostatic force on 10 kg charge should be $F_e = 100 \text{ N}$ upwards

$\therefore$ Net electrostatic force on remaining four charges = 100 N downwards

$\therefore$ Net force on remaining four charges

= Net electrostatic force + net weight

= 100 N + 100 N = 200 N downwards

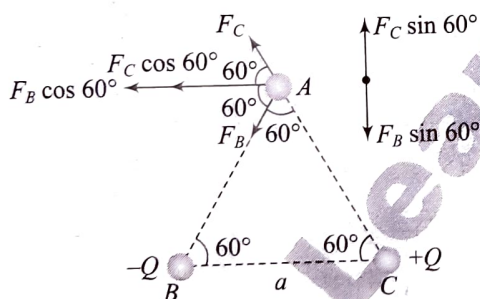
$\therefore$ Acceleration of centre of mass of the four charges immediately after the release

$$= \frac{\text{Net Force}}{\text{Net mass}} = \frac{200}{10} = 20 \text{ m/s}^2 \text{ downwards}$$

Single Correct Answer Type

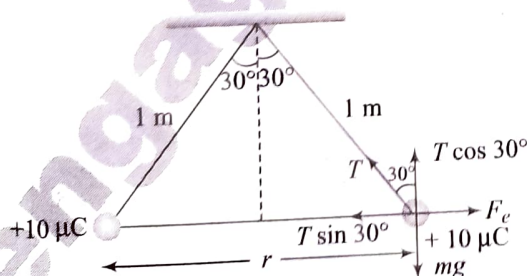
3. (c) We put a unit positive charge at O . Resultant force due to the charge placed at A and C is zero and resultant charge due to B and D is towards D along the diagonal BD .

4. (c) $|\vec{F}_B| = |\vec{F}_C| = k \cdot \frac{Q^2}{a^2}$



Hence force experienced by the charge at A in the direction normal to BC is zero.

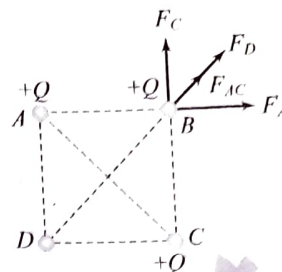
5. (b) In the following figure, in equilibrium $F_e = T \sin 30^\circ$, $r = 1 \text{ m}$



$$\Rightarrow 9 \times 10^9 \cdot \frac{Q^2}{r^2} = T \times \frac{1}{2}$$

$$\Rightarrow 9 \times 10^9 \cdot \frac{(10 \times 10^{-6})^2}{1^2} = T \times \frac{1}{2} \Rightarrow T = 1.8 \text{ N}$$

6. (c) After following the guidelines mentioned in the question,



$$F_{\text{net}} = F_{AC} + F_D = \sqrt{F_A^2 + F_C^2} + F_D$$

$$\text{Since } F_A = F_C = \frac{kQ^2}{a^2} \text{ and } F_D = \frac{kQ^2}{(a\sqrt{2})^2}$$

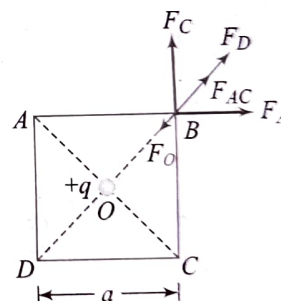
$$F_{\text{net}} = \frac{\sqrt{2}kQ^2}{a^2} + \frac{kQ^2}{2a^2} = \frac{kQ^2}{a^2} \left(\sqrt{2} + \frac{1}{2} \right)$$

$$= \frac{Q^2}{4\pi\epsilon_0 a^2} \left(\frac{1 + 2\sqrt{2}}{2} \right)$$

7. (b) If all charges are in equilibrium, system is also in equilibrium. Charge at centre: charge q is in equilibrium because no net force is acting on the corner charge:

If we consider the charge at corner B . This charge will experience the following forces

$$F_A = k \frac{Q^2}{a^2}, F_C = \frac{kQ^2}{a^2}, F_D = \frac{kQ^2}{(a\sqrt{2})^2} \text{ and } F_O = \frac{KQq}{(a\sqrt{2})^2}$$



Force at B away from the centre = $F_{AC} + F_D$

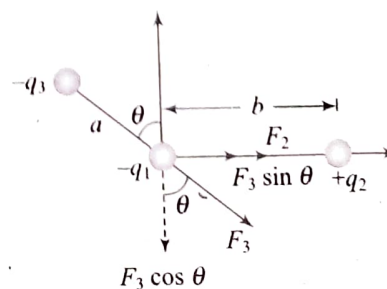
$$= \sqrt{F_A^2 + F_C^2} + F_D = \sqrt{2} \frac{kQ^2}{a^2} + \frac{kQ^2}{2a^2} = \frac{kQ^2}{a^2} \left(\sqrt{2} + \frac{1}{2} \right)$$

Force at B towards the centre = $F_O = \frac{2KQq}{a^2}$

For equilibrium of charge at B , $F_{AC} + F_D = F_O$

$$\Rightarrow \frac{KQ^2}{a^2} \left(\sqrt{2} + \frac{1}{2} \right) = \frac{2KQq}{a^2} \Rightarrow q = \frac{Q}{4} (1 + 2\sqrt{2})$$

8. (c)



S.6 Electrostatics and Current Electricity

F_2 = Force applied by q_2 on $-q_1$

F_3 = Force applied by $(-q_3)$ on $-q_1$

x-component of net force on $-q_1$ is

$$F_x = F_2 + F_3 \sin \theta = k \frac{q_1 q_2}{b^2} + k \frac{q_1 q_3}{a^2} \sin \theta$$

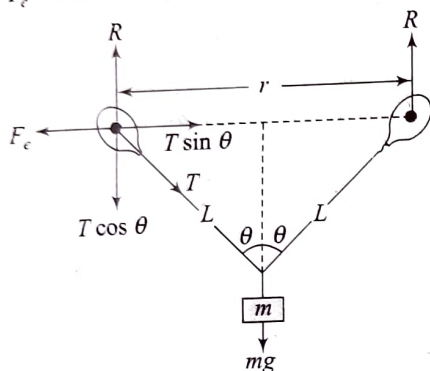
$$\Rightarrow F_x = k \left[\frac{q_1 q_2}{b^2} + \frac{q_1 q_3}{a^2} \sin \theta \right]$$

$$\Rightarrow F_x = k \cdot q_1 \left[\frac{q_2}{b^2} + \frac{q_3}{a^2} \sin \theta \right] \Rightarrow F_x \propto \left(\frac{q_2}{b^2} + \frac{q_3}{a^2} \sin \theta \right)$$

9. (a) In equilibrium

$$2R = mg$$

$$F_e = T \sin \theta$$



$$R = T \cos \theta$$

From equations (i) and (iii)

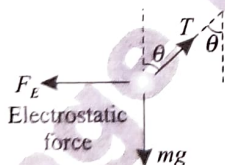
$$2T \cos \theta = mg$$

Dividing equation (ii) by equation (iv),

$$\frac{1}{2} \tan \theta = \frac{F_e}{mg}$$

$$\Rightarrow \frac{1}{2} \tan \theta = \frac{k \frac{Q^2}{r^2}}{mg} \Rightarrow \theta = \left(\frac{mgr^2}{2k} \tan \theta \right)^{1/2}$$

10. (a) Since both the small spheres are at the same horizontal level, the electrostatic forces on both spheres are in horizontal direction. The FBD of left sphere is shown in the figure



The sphere is in equilibrium

$$T \cos \theta = mg$$

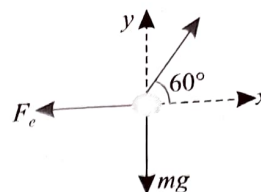
$$\text{and } T \sin \theta = F_e$$

$$\text{From (i) and (ii), } \tan \theta = \frac{F_e}{mg}$$

The magnitude of electrostatic force on each sphere is the same irrespective of its charge

for $\theta_1 = \theta_2$ the necessary condition is $m_1 = m_2$

11. (a) Two bowls, exert a normal force N on each bead and are directed along the radius line or at 60° above the horizontal. Consider the free-body diagram of the bead on the left with the electric force F_e applied.



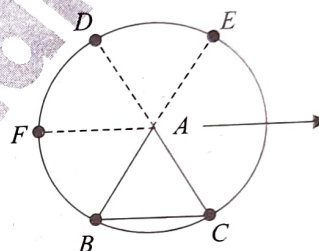
$$\Sigma F_y = N \sin 60^\circ - mg = 0, \Rightarrow N = mg / \sin 60^\circ$$

$$\Sigma F_x = -F_e + N \cos 60^\circ = 0$$

$$\Rightarrow \frac{Kq^2}{R^2} = N \cos 60^\circ = \frac{mg}{\tan 60^\circ} = \frac{mg}{\sqrt{3}}$$

$$\text{Thus } q = R \left(\frac{mg}{k_e \sqrt{3}} \right)^{1/2}$$

12. (c) Two similar charges should be placed at D and E so that resultant force at A is zero. A similar charge should not be placed at F , so that resultant force at A will be $\frac{q^2}{4\pi\epsilon_0 a^2}$ towards x -axis.



(iii)

(iv)

$$13. (b) \vec{F}_{DO} = \frac{q^2}{4\pi\epsilon_0 a^2} \text{ and } \angle DOC = \theta_2 - \theta_1$$

$$\text{But } \vec{F}_{DO} \cos(\theta_2 - \theta_1) = \frac{q^2 \sqrt{3}}{8\pi\epsilon_0 a^2} \text{ (given)}$$

$$\text{So, } \cos(\theta_2 - \theta_1) = \frac{\sqrt{3}}{2}$$

$$\Rightarrow \theta_2 - \theta_1 = 30^\circ$$

(i)

$$\vec{F}_{BO} = \frac{q^2}{4\pi\epsilon_0 a^2} \text{ and } \angle COB = \theta_3 - \theta_2$$

$$\text{But } \vec{F}_{BO} \cos(\theta_3 - \theta_2) = \frac{q^2 \sqrt{3}}{8\pi\epsilon_0 a^2} \text{ (given)}$$

$$\text{So, } \cos(\theta_3 - \theta_2) = \frac{\sqrt{3}}{2}$$

$$\Rightarrow \theta_3 - \theta_2 = 30^\circ$$

(ii)

From (i) and (ii)

$$\theta_2 - \theta_1 = \theta_3 - \theta_2 \text{ or } 2\theta_2 = \theta_1 + \theta_3$$

14. (d) Net electrostatic force is along negative y -axis. Thus electrostatic force along x -axis will be zero, if

$$\frac{qQ \sin \theta_1}{4\pi\epsilon_0 a^2} = \frac{qQ' \sin \theta_2}{4\pi\epsilon_0 a_0^2}$$

$$\frac{\theta_1}{\theta_2} = \sin^{-1} \left(\frac{Q' a^2}{Q a_0^2} \right)$$

$$\text{If } \theta_1 = \frac{\theta_2}{2},$$

$$\frac{1}{2} = \sin^{-1} \left(\frac{Q'a^2}{Qa_0^2} \right)$$

$$\frac{\pi}{6} = \frac{Q'a^2}{Qa_0^2} \quad \text{or} \quad \frac{Q'}{Q} = \frac{\pi a_0^2}{6a^2}$$

DPP 1.4

Subjective Type

1. E at $AB = \frac{a}{l}(l+l) = 2a \therefore F$ on $AB = 2a\lambda l$

E at $CD = \frac{a}{l}(2l+l) = 3a \therefore F$ on $CD = 3a\lambda l$

On BC and AD electric field is nonuniform and x is not constant. But on BC and AD electric field will have the same type of variation.

$$\therefore F_{AD} = F_{BC} = \int_{x=l}^{2l} (\lambda dx) \cdot \frac{a}{l}(x+l)$$

$$= \frac{a\lambda}{l} \left[\frac{x^2}{2} + lx \right]_l^{2l} = \frac{a\lambda}{l} \left[\frac{3l^2}{2} + l^2 \right] = \frac{5}{2} a\lambda l$$

$\therefore$ Total force on the loop $= 2a\lambda l + 3a\lambda l + 2 \left(\frac{5}{2} a\lambda l \right)$

$$F = 10 a\lambda l$$

Using values $F = 4 \times 10^{-6} \text{ N}$

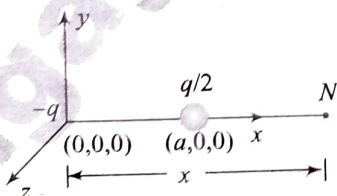
Single Correct Answer Type

2. (b) $E = \frac{1}{4\pi\epsilon_0} \times \frac{q}{r^2} = 9 \times 10^9 \times \frac{q}{r^2}$

$$\therefore q = \frac{E \times r^2}{9 \times 10^9} = \frac{3 \times 10^6 \times (2.5)^2}{9 \times 10^9} = 2.0833 \times 10^{-3}$$

q should be less than 2.0833×10^{-3} . In the given set of options 2×10^{-3} is the maximum charge which is smaller than 2.0833×10^{-3}

3. (c)

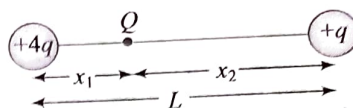


Suppose the field vanishes at a (distance x), we have

$$\frac{kq}{x^2} = \frac{kq/2}{(x-a)^2} \quad \text{or} \quad 2(x-a)^2 = x^2 \quad \text{or} \quad \sqrt{2}(x-a) = x$$

$$\text{or} \quad (\sqrt{2}-1)x = \sqrt{2}a \quad \text{or} \quad x = \left(\frac{\sqrt{2}a}{\sqrt{2}-1} \right)$$

4. (c) Let third charge be placed at a distance x_1 from $+4q$ charge as shown and it should be negative



For neutral point between $4q$ and q ,

$$\frac{k4q}{x_1^2} = \frac{kq}{(L-x_1)^2}$$

$$\text{Now } x_1 = \frac{L}{1 + \sqrt{\frac{q}{4q}}} = \frac{2L}{3}, \quad x_2 = \frac{L}{3}$$

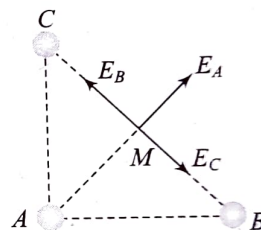
For equilibrium of q , $\frac{k4q}{L^2} = \frac{kQ}{x_2^2}$

$$\Rightarrow Q = 4q \left(\frac{L/3}{L} \right)^2 = \frac{4q}{9} \Rightarrow Q = -\frac{4q}{9}$$

5. (b) E_A = Electric field at M due to charge placed at A

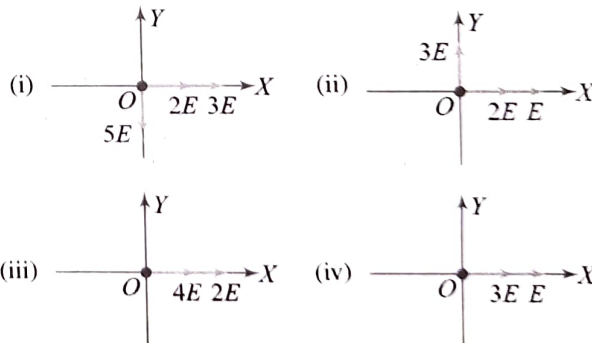
E_B = Electric field at M due to charge placed at B

E_C = Electric field at M due to charge placed at C



As seen from figure $|\overline{E_B}| = |\overline{E_C}|$, so net electric field at M , $E_{\text{net}} = E_A$, in the direction of vector 2.

6. (c) If electric field due to charge $|q|$ at origin is Ea , then electric field due to charges $|2q|$, $|3q|$, $|4q|$ and $|5q|$ are respectively $2E$, $3E$, $4E$ and $5E$



$$E_{(i)} = \sqrt{(5E)^2 + (5E)^2} = 5\sqrt{2}E$$

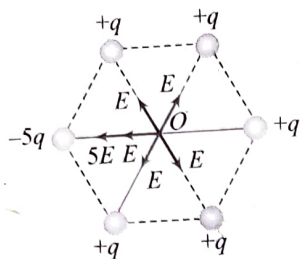
$$E_{(ii)} = \sqrt{(3E)^2 + (3E)^2} = 3\sqrt{2}E$$

$$E_{(iii)} = 4E + 2E = 6E \quad \text{and} \quad E_{(iv)} = 3E + E = 4E$$

$$\Rightarrow E_{(i)} > E_{(iii)} > E_{(ii)} > E_{(iv)}$$

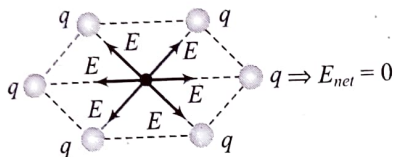
S.8 Electrostatics and Current Electricity

7. (d) To obtain net field $6E$ at centre O , the charge to be placed at the remaining sixth corner is $-5q$. (see the following figure)

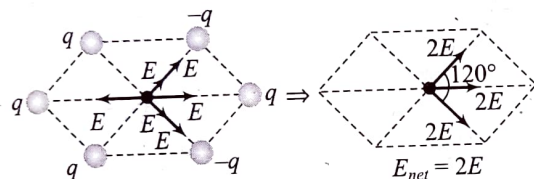


8. (b) Electric field at a point due to positive charge acts away from the charge and due to negative charge it acts towards the charge.

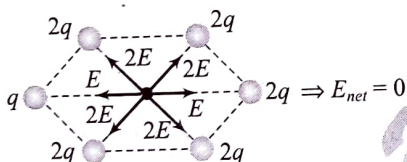
Case (1)



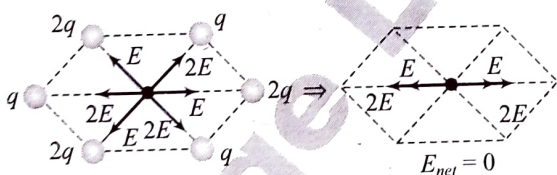
Case (2)



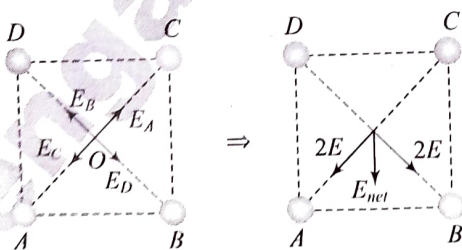
Case (3)



Case (4)



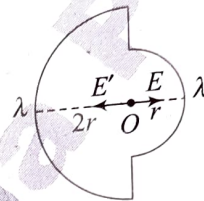
9. (b)



$$E_A = E, E_B = 2E, E_C = 3E, E_D = 4E$$

$$\begin{aligned} 10. (a) \text{ Net field at origin } E &= \frac{q}{4\pi\epsilon_0} \left[\frac{1}{1^2} + \frac{1}{2^2} + \frac{1}{4^2} + \dots \infty \right] \\ &= \frac{q}{4\pi\epsilon_0} \left[1 + \frac{1}{4} + \frac{1}{16} + \dots \infty \right] \\ &= \frac{q}{4\pi\epsilon_0} \left[\frac{1}{1 - \frac{1}{4}} \right] = 12 \times 10^9 \text{ q N/C} \end{aligned}$$

11. (d) The electric field due to both straight wires shall cancel at common centre O . The electric field due to larger and smaller semi-circular rings at O be E and E' respectively.



$$E = \frac{1}{4\pi\epsilon_0} \frac{2\lambda}{2r} \quad E' = \frac{1}{4\pi\epsilon_0} \frac{2\lambda}{r}$$

$\therefore$ Magnitude of electric field at O is

$$= E - \frac{1}{4\pi\epsilon_0} \left(\frac{2\lambda}{r} - \frac{\lambda}{r} \right) = \frac{1}{4\pi\epsilon_0} \frac{\lambda}{r}$$

12. (d) Electric field at a point on z -axis distant r from origin is

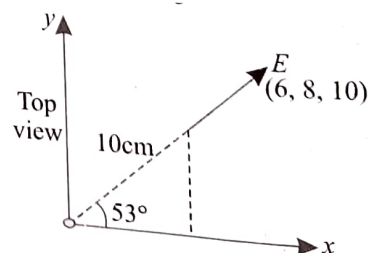
$$E = \frac{1}{4\pi\epsilon_0} \left(\frac{Qr}{(r^2 + R^2)^{3/2}} - \frac{\sqrt{8}Qr}{(r^2 + 4R^2)^{3/2}} \right) = 0$$

Solving we get $r = \sqrt{2} R$

$$13. (d) \quad E = \frac{\lambda}{2\pi\epsilon_0 d} = \frac{2K\lambda}{d}$$

$$= \frac{2 \times 9 \times 10^9 \times (10/9) \times 10^{-9}}{10 \times 10^{-2}} = 200 \text{ V/m}$$

As field is radial out, there is no component of it in Z -direction.



$$\vec{E} = (200 \cos 53^\circ \hat{i} + 200 \sin 53^\circ \hat{j}) \text{ V/m}$$

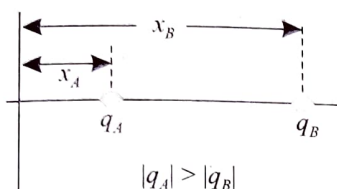
$$= \left(200 \times \frac{3}{5} \hat{i} + 200 \times \frac{4}{5} \hat{j} \right) = (120\hat{i} + 160\hat{j}) \text{ V/m}$$

Multiple Correct Answers Type

14. (a, c, d)

(a) If both are positive, then null point lies in between them where direction of the electric fields due to both are opposite in direction.

(c) If q_A is positive and q_B is negative, then in both regions $x < x_A$ and $x > x_B$, field directions are opposite. But null point would lie nearer to the charge of the lesser magnitude.



DPP 1.5

Subjective Type

1. (i) Here, in the figure, the electric lines of force emanate from A and C. Therefore, charges A and C must be positive.
 (ii) The number of electric lines of forces emanating is maximum for charge C here, so C must have the largest magnitude.
 (iii) Point between two like charges where electrostatic force is zero is called *neutral point*. So, the neutral point lies between A and C only.

Now the position of neutral point depends on the strength of the forces of charges. Here, more number of electric lines of forces shows higher strength of charge C than A. So, neutral point lies near A.

2. (a) (i) The point O is equidistant from all the charges at the end point of pentagon. Thus, due to symmetry, the forces due to all the charges are cancelled out. As a result, electric field at O is zero.

(ii) When charge q is removed, a negative charge will develop at A giving electric field $E = \frac{q \times 1}{4\pi\epsilon_0 r^2}$ along OA.

(iii) If charge q at A is replaced by $-q$, then two negative charges $-2q$ will be developed. Thus, the value of electric field

$$E = \frac{2q}{4\pi\epsilon_0 r^2} \text{ along OA.}$$

- (b) When pentagon is replaced by n sided regular polygon with charge q at each of its corners, the electric field at O would continue to be zero as symmetry of the charges is due to the regularity of the polygon. It doesn't depend on the number of sides or the number of charges.

Single Answer Correct Type

3. (a) Since the lines of forces are terminating on the charges both have to be negative.

4. (b) B. Pattern (A) can be eliminated because field lines cannot simultaneously originate from and converge at a single point; (C) can be eliminated because there are no charges in the region, and so there are no sources of field lines; (D) can be eliminated because electrostatic field lines do not close on themselves.
 5. (a) Metal plate acts as an equipotential surface, therefore the field lines should enter normal to the surface of the metal plate.
 6. (c) q is +ve because lines of force emerge from it and $|Q| < |q|$ because more lines emerge from q and less lines terminate at Q .

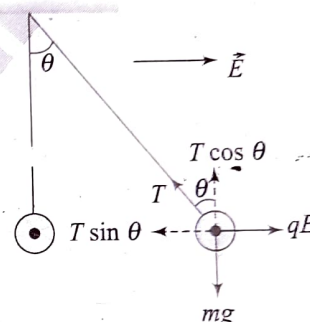
7. (d) At mid-point, $E = 0$

Before mid-point, E is positive. This is maximum near the charge and decreases towards mid-point.

After mid-point, E is negative, the curve crosses x -axis at $x = d/2$. From centre to end, E decreases.

The variation is shown by the curve.

8. (b) $T \sin \theta = qE$, $T \cos \theta = mg$



$$\therefore \tan \theta = \frac{qE}{mg}$$

$$\tan \theta = \frac{39.2 \times 10^{-10} \times 20 \times 10^3}{8 \times 10^{-6} \times 9.8} = 1$$

$$\Rightarrow \theta = 45^\circ$$

9. (c) $E_1 = \frac{\eta q}{4\pi\epsilon_0 a^2}$, $E_2 = \frac{\eta q}{4\pi\epsilon_0 a^2}$. Therefore $E = \vec{E}_1 + \vec{E}_2$

$$= \sqrt{E_1^2 + E_2^2 + 2E_1E_2 \cos 60^\circ} = \frac{\sqrt{3}\eta q}{4\pi\epsilon_0 a^2}$$

Since $\eta^{-1} < \sqrt{3}$, $1 < \sqrt{3}\eta$, $\sqrt{3}\eta > 1$.

$$\Rightarrow \frac{\sqrt{3}\eta q}{3\pi\epsilon_0 a^2} > \frac{q}{4\pi\epsilon_0 a^2} \Rightarrow E_3 > E_0 \left(E_0 = \frac{q}{4\pi\epsilon_0 a^2} \right)$$

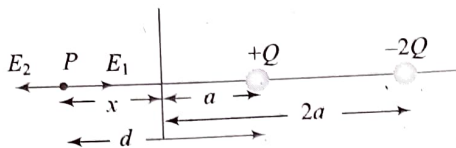
10. (b) Suppose electric field is zero at a point P, which lies at a distance d from the charge $+Q$.

$$\text{At } P \quad \frac{kQ}{d^2} = \frac{k(2Q)}{(a+d)^2}$$

$$\Rightarrow \frac{1}{d^2} = \frac{2}{(a+d)^2} \Rightarrow d = \frac{a}{(\sqrt{2}-1)}$$

DPP 1.6

Subjective Type



Since $d > a$, i.e., point P must lie on negative x -axis as shown at a distance x from origin, hence $x = d - a = \frac{a}{(\sqrt{2} - 1)} - a = \sqrt{2}a$.

Actually P lies on negative x -axis so $x = -\sqrt{2}a$.

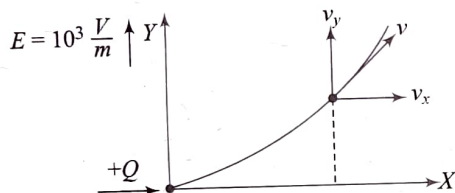
11. (a) When the point is situated at a point on diameter away from the centre of hemisphere charged uniformly positively, the electric field is perpendicular to the diameter. The component of electric intensity parallel to the diameter cancels out.

12. (c) The time required to fall through distance d is

$$d = \frac{1}{2} \left(\frac{qE}{m} \right) t^2 \text{ or } t = \sqrt{\frac{2dm}{qE}}$$

Since $t^2 \propto m$, a proton takes more time.

13. (c) Body moves along the parabolic path.



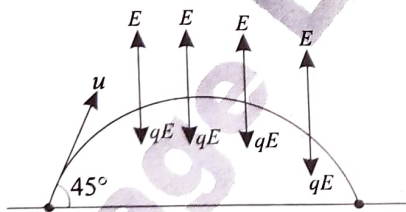
For vertical motion: By using $v = u + at$

$$\Rightarrow v_y = 0 + \frac{QE}{m} \cdot t = \frac{10^{-6} \times 10^3}{10^{-3}} \times 10 = 10 \text{ m/sec}$$

For horizontal motion: Its horizontal velocity remains the same, i.e., after 10 sec, horizontal velocity of body $v_x = 10 \text{ m/sec}$.

Velocity after 10 sec $v = \sqrt{v_x^2 + v_y^2} = 10\sqrt{2} \text{ m/sec}$

14. (a) For maximum distance, angle of projection should be 45°



For vertical displacement: $\vec{s} = \vec{ut} + \frac{1}{2} \vec{at}^2$

$$0 = u \sin 45^\circ t + \frac{1}{2} \cdot \frac{q \cdot \sigma}{2\epsilon_0} t^2$$

$$t = 0 \text{ or } \frac{2\sqrt{2}mv\epsilon_0}{\sigma q} t = \frac{2\sqrt{2}mv\epsilon_0}{\sigma q} \text{ so time of flight} = \frac{2\sqrt{2}mv\epsilon_0}{\sigma q}$$

$$1. \text{ Force} = p \frac{dE}{dz} = 10^{-7} \times 10^5 = 10^{-2}$$

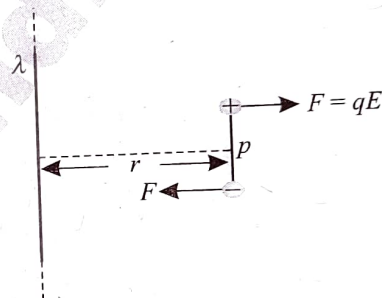
Torque is zero because the forces on the dipole are antiparallel and act in the same line.

$$2. \text{ Force} = p \left| \frac{dE}{dx} \right| \{y \text{ is not changing since } \vec{p} \text{ is directed along } x \text{ axis}\}$$

$$= p \left| [4y^2 \hat{i} + 8xy \hat{j}] \right| = p 4y \left| [y \hat{i} + 2x \hat{j}] \right|$$

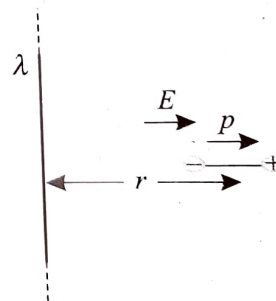
$$= 4py \sqrt{y^2 + 4x^2}$$

3. (a) If the dipole moment vector $\vec{p}$ is oriented along the thread



Net force on dipole $F = qE - qE = 0$

- (b) If the dipole moment vector $\vec{p}$ is oriented along the radius vector r



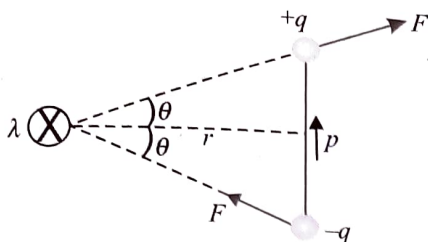
Here force on dipole, $F = p \left| \frac{dE}{dr} \right|$

$$E = \text{due to wire, } E = \frac{2K\lambda}{r}$$

$$\frac{dE}{dr} = -\frac{2K\lambda}{r^2}$$

$$\Rightarrow F = \frac{2K\lambda}{r^2} p = \frac{\lambda p}{2\pi\epsilon_0 r^2} \text{ towards wire}$$

- (c) If the dipole moment vector $\vec{p}$ is oriented at the right angles to the thread and the radius vector r .



Net force on dipole $F_{\text{net}} = 2F \sin \theta$.

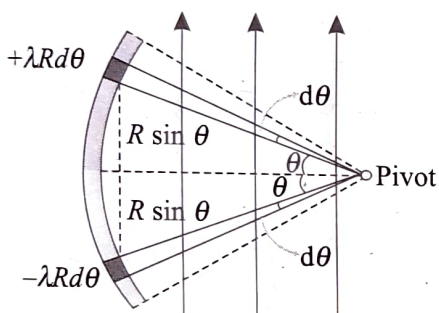
Here θ is very small as size of the dipole is small, $\sin \theta \approx \theta$

$$\therefore F_{\text{net}} = 2 \frac{2K\lambda}{r} q \times \frac{q}{r} = \frac{2K\lambda p}{r^2}$$

$$\Rightarrow F_{\text{net}} = \frac{\lambda p}{2\pi\epsilon_0 r^2}$$

4. We consider two differential elements on the rod as shown in the figure. These elements constitute an electric dipole whose dipole moment is

$$|d\vec{p}| = (\lambda R d\theta)(2R \sin \theta)$$



Net dipole moment of the system is

$$\begin{aligned} |\vec{p}| &= \int_0^{2\theta_0} (\lambda R d\theta) 2R \sin \theta \\ &= 2\lambda R^2 (1 - \cos 2\theta_0) = 4\lambda R^2 \sin^2 \theta_0 \end{aligned}$$

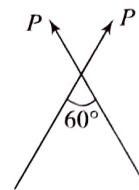
Time period of oscillation of a dipole in a uniform magnetic field is

$$\begin{aligned} T &= 2\pi \sqrt{\frac{I}{pE}} \\ &= 2\pi \sqrt{\frac{mR^2}{4\lambda R^2 \sin^2 \theta_0 E}} \\ &= \pi \sqrt{\frac{m}{\lambda \sin^2 \theta_0 E}} \end{aligned}$$

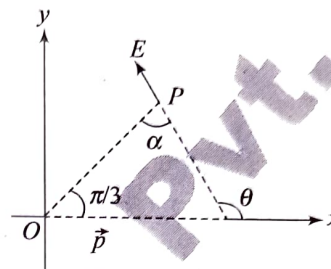
Single Correct Answer Type

5. (c) The charge $+2q$ can be broken into $+q$ and $+q$. Now as shown in the figure we have two equal dipoles inclined at an angle of 60° . Therefore resultant dipole moment will be

$$\begin{aligned} p_{\text{net}} &= \sqrt{p^2 + p^2 + 2pp \cos 60} \\ &= \sqrt{3}p = \sqrt{3}qa \end{aligned}$$



6. (b) According to question we can draw the following figure.

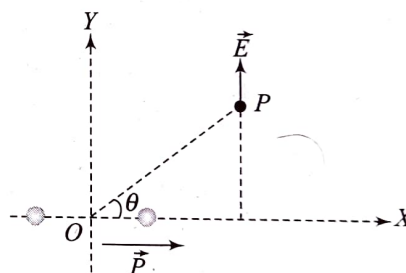


As we have discussed earlier in theory $\theta = \frac{\pi}{3} + \alpha$

$$\tan \alpha = \frac{1}{2} \tan \frac{\pi}{3} \Rightarrow \alpha = \tan^{-1} \frac{\sqrt{3}}{2}$$

$$\text{So, } \theta = \frac{\pi}{3} + \tan^{-1} \frac{\sqrt{3}}{2}$$

7. (b) As we know that in this case electric field makes an angle $\theta + \alpha$ with the direction of dipole



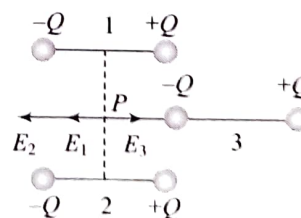
$$\text{Where } \tan \alpha = \frac{1}{2} \tan \theta$$

$$\text{Here } \theta + \alpha = 90^\circ \Rightarrow \alpha = 90 - \theta$$

$$\text{Hence } \tan(90 - \theta) = \frac{1}{2} \tan \theta \Rightarrow \cot \theta = \frac{1}{2} \tan \theta$$

$$\Rightarrow \tan^2 \theta = 2 \Rightarrow \tan \theta = \sqrt{2}$$

8. (c) Point P lies at equatorial positions of dipoles 1 and 2 and axial position of dipole 3.



Hence field at P,

due to dipole 1,

$$E_1 = \frac{k \cdot p}{x^3} \text{ (towards left)}$$

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due to dipole 2,

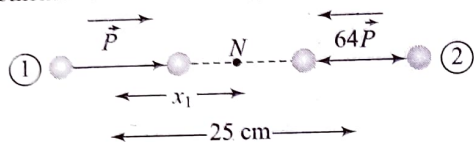
$$E_2 = \frac{k \cdot P}{x^2} \text{ (towards left)}$$

due to dipole 3,

$$E_3 = \frac{k \cdot (2P)}{x^3} \text{ (towards right)}$$

So net field at P will be zero.

9. (a) Suppose neutral point N lies at a distance x from dipole of moment P or at a distance x_2 from dipole of $64P$.



At N |E. F. due to dipole (1)| = |E. F. due to dipole (2)|

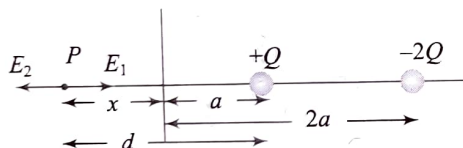
$$\Rightarrow \frac{1}{4\pi\epsilon_0} \cdot \frac{2P}{x^3} = \frac{1}{4\pi\epsilon_0} \cdot \frac{2(64P)}{(25-x)^3}$$

$$\Rightarrow \frac{1}{x^3} = \frac{64}{(25-x)^3} \Rightarrow x = 5 \text{ cm}$$

10. (b) Suppose electric field is zero at a point P , which lies at a distance d from the charge $+Q$.

$$\text{At } P, \frac{kQ}{d^2} = \frac{k(2Q)}{(a+d)^2}$$

$$\Rightarrow \frac{1}{d^2} = \frac{2}{(a+d)^2} \Rightarrow d = \frac{a}{(\sqrt{2}-1)}$$



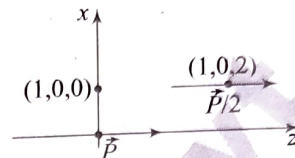
Since $d > a$ i.e., point P must lie on negative x -axis as shown at a distance x from the origin, hence $x = d - a$

$$= \frac{a}{(\sqrt{2}-1)} - a = \sqrt{2}a. \text{ Actually } P \text{ lies on negative } x\text{-axis, so}$$

$$x = -\sqrt{2}a$$

11. (d) Electric field due to ring and dipole moment are parallel to each other.

12. (b)



The given point is at axis of $\frac{\vec{P}}{2}$ dipole and at equatorial line of $\vec{P}$ dipole so total field at given point is

$$\vec{E} = \frac{k\vec{P}}{(1)^3} + \frac{2k(\vec{P}/2)}{(2)^3} = k\vec{P} \left(-1 + \frac{1}{8} \right) = \frac{-7\vec{P}}{32\pi\epsilon_0}$$

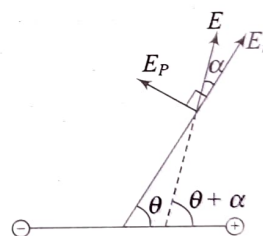
13. (b) Electric field of a point charge is nonuniform, hence net force can never be zero.

14. (d) For the given points

$$\theta + \alpha = \pi/2 \Rightarrow \alpha = \pi/2 - \theta$$

$$\text{As } \tan \alpha = \frac{\tan \theta}{2}$$

$$\Rightarrow \tan\left(\frac{\pi}{2} - \theta\right) = \frac{\tan \theta}{2} \Rightarrow \tan \theta = \sqrt{2}$$



CHAPTER 2

DPP 2.1

Subjective Type

- $\phi = \vec{E} \cdot \vec{A} = (4\hat{i}) \cdot (2\hat{i} + 3\hat{j}) = 8 \text{ N} \cdot \text{m}^2$
 - $\phi = \vec{E} \cdot \vec{A} = (4\hat{k}) \cdot (2\hat{i} + 3\hat{j}) = 0$
- We use $\Phi = \int \vec{E} \cdot d\vec{A}$ and note that the side length of the cube is $(3.0 \text{ m} - 1.0 \text{ m}) = 2.0 \text{ m}$.

 - On the top face of the cube $y = 2.0 \text{ m}$ and $d\vec{A} = (dA)\hat{j}$.
Therefore, we have $\vec{E} = 4\hat{i} - 3((2.0)^2 + 2)\hat{j} = 18\hat{j}$. Thus the flux is

$$\Phi = \int_{\text{top}} \vec{E} \cdot d\vec{A} = \int_{\text{top}} (4\hat{i} - 18\hat{j}) \cdot (dA)\hat{j}$$

$$= -18 \int_{\text{top}} dA = (-18)(2.0)^2 \text{ N} \cdot \text{m}^2/\text{C}$$

$$= -72 \text{ N} \cdot \text{m}^2/\text{C}$$
 - On the bottom face of the cube $y = 0$ and $d\vec{A} = (dA)(-\hat{j})$.
Therefore, we have $\vec{E} = 4\hat{i} - 3(0^2 + 2)\hat{j} = 4\hat{i} - 6\hat{j}$. Thus, the flux is

$$\Phi = \int_{\text{bottom}} \vec{E} \cdot d\vec{A} = \int_{\text{bottom}} (4\hat{i} - 6\hat{j}) \cdot (dA)(-\hat{j})$$

$$= 6 \int_{\text{bottom}} dA = 6(2.0)^2 \text{ N} \cdot \text{m}^2/\text{C} = +24 \text{ N} \cdot \text{m}^2/\text{C}$$
 - On the left face of the cube $d\vec{A} = (dA)(-\hat{i})$. So

$$\Phi = \int_{\text{left}} \vec{E} \cdot d\vec{A} = \int_{\text{left}} (4\hat{i} - E_y\hat{j}) \cdot (dA)(-\hat{i})$$

$$= 4 \int_{\text{left}} dA = -4(2.0)^2 \text{ N} \cdot \text{m}^2/\text{C}$$

$$= -16 \text{ N} \cdot \text{m}^2/\text{C}$$
 - On the back face of the cube $d\vec{A} = (dA)(-\hat{k})$. But since $\vec{E}$ has no z component $\vec{E} \cdot d\vec{A} = 0$. Thus, $\Phi = 0$.
 - We now have to add the flux through all six faces. One can easily verify that the flux through the front face is zero, while that through the right face is the opposite of that through the left one, or $+16 \text{ N} \cdot \text{m}^2/\text{C}$. Thus the net flux through the cube is

$$\Phi = (-72 + 24 - 16 + 0 + 0 + 16) \text{ N} \cdot \text{m}^2/\text{C}$$

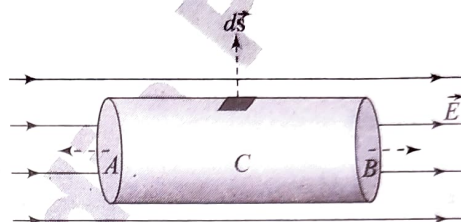
$$= -48 \text{ N} \cdot \text{m}^2/\text{C}$$
- We use $\Phi = \vec{E} \cdot \vec{A}$, where $\vec{A} = A\hat{j} = (\sqrt{2} \text{ m}) \text{ N} \cdot \text{m}^2/\text{C}$.

 - $\Phi = (6.00 \text{ N/C})\hat{i} \cdot (\sqrt{2} \text{ m})^2 \hat{j} = 0$
 - $\Phi = (-2.00 \text{ N/C})\hat{j} \cdot (\sqrt{2} \text{ m})^2 \hat{j} = -4.0 \text{ N} \cdot \text{m}^2/\text{C}$
 - $\Phi = [(-3.00 \text{ N/C})\hat{i} + (400 \text{ N/C})\hat{k}] \cdot (\sqrt{2} \text{ m})^2 \hat{j} = 0$
 - The total flux of a uniform field through a closed surface is always zero.
- There is no flux through the sides, so we have two "inward" contributions to the flux, one from the top (of magnitude (34)

$(3.0)^2$) and one from the bottom (of magnitude $(20)(3.0)^2$). With "inward" flux being negative, the result is $\Phi = -486 \text{ N} \cdot \text{m}^2/\text{C}$.

Single Correct Answer Type

- $\phi = \vec{E} \cdot d\vec{s} = (i + \sqrt{2}j + \sqrt{3}k) \cdot (100\hat{k}) = 17.32 \text{ Nm}^2/\text{C}$
 - Flux through surface A $\phi_A = E \times \pi R^2$ and $\phi_B = -E \times \pi R^2$

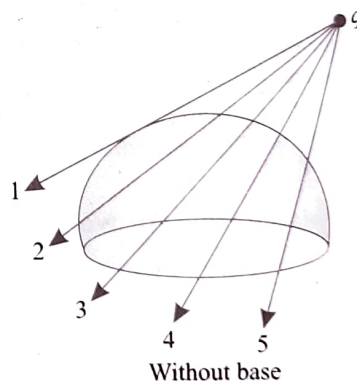


Flux through curved surface $C = \int \vec{E} \cdot d\vec{s} = \int E ds \cos 90^\circ = 0$

$\therefore$ Total flux through cylinder $= \phi_A + \phi_B + \phi_C = 0$

- For the given surface, if the number of field lines cutting the surface is twice the net flux contribution will be zero.

For example, if we observe the diagram, then for drawn field of lines, 5 lines of force are entering the surface. Line 1 is tangential to the surface, hence no contribution to the flux. Line 2 cutting the surface is twice, hence net flux contribution will be zero. Lines 3, 4 and 5 are cutting the surface only one time, hence contributing to net flux.



In case (a) and (b) the surfaces are not closed, hence in these cases there will be net flux associated with the surfaces. In cases (c), surface is closed but a charge is enclosed by the surface, hence there will be flux due to the charged enclosed and outer charge does not contribute to the flux.

In (d) surface is closed and no charge is enclosed within the surface. There will be no flux due to the outer charge placed near the surface as electric field lines will cut the surface twice.

- Flux coming out of the cube, $\phi_1 = \frac{\lambda \cdot a\sqrt{3}}{\epsilon_0}$ (i)

and from sphere $\phi_2 = \frac{\lambda \cdot 2a}{\epsilon_0}$ (ii)

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$$\therefore \frac{\phi_1}{\phi_2} = \frac{\sqrt{3}}{2}$$

9. (c) We have electric field due to ring $E = k \frac{Qx}{(R^2 + x^2)^{3/2}}$

$$\phi = \vec{E} \cdot \vec{ds}$$

Since $r \ll R$ so we can consider electric field to be constant over the surface of smaller ring.

$$\text{Hence } \phi \propto E \propto \frac{x}{(R^2 + x^2)^{3/2}}$$

So, the best represented graph is (c).

10. (c) After covering with a hemispherical shell; $\phi_{\text{shell}} + \phi_{\text{disc}} = 0$ (from Gauss's law)

$$\therefore \phi_{\text{shell}} = -\phi_{\text{disc}} = -\phi$$

11. (d) In each case: $\oint \vec{E} \cdot d\vec{A} = \frac{q_{\text{enclosed}}}{\epsilon_0}$

$$E \oint dA = \frac{Q}{\epsilon_0}$$

$$E(4\pi r^2) = \frac{Q}{\epsilon_0}$$

$$E = \frac{1}{4\pi\epsilon_0} \frac{Q}{r^2}$$

As charged enclosed within the Gaussian surface is the same, the radius of Gaussian surface is equal. Hence, the magnitude of electric field will be equal.

12. (a) $\oint \vec{E} \cdot d\vec{S} = \frac{q_{\text{enclosed}}}{\epsilon_0}$

Let us take a spherical Gaussian surface passing through P and enclosing the charge.

For (I) and (II) charge enclosed is the same and equal to Q , hence magnitude of electric field will be equal.

The charge density in case (III) is greater than case (IV) as the volume of sphere (III). Hence charge enclosed in case (III) is greater than case (IV), it means the magnitude of electric field in case (III) is greater than in case (IV).

Multiple Correct Answers Type

13. (b, d)

Situation I: The magnitude of flux passing through hemispherical surface is equal to flux passing through the plane circular surface. Hence $\phi = E\pi R^2$

Situation II: The electric field lines cuts the hemispherical surface twice, hence no flux will be associated with situation II.

14. (a, b, c)

As charge enclosed by each Gaussian surfaces is the same, hence net flux enclosed through all the Gaussian surfaces will be the same.

$$\text{Gauss theorem } \oint \vec{E} \cdot d\vec{S} = \frac{q_{\text{enclosed}}}{\epsilon_0}$$

The spherical Gaussian surfaces are symmetrical about charge, hence flux will be uniform for these surfaces. But for cubical Gaussian surface, this symmetry does not present as the distance of the charge vary from point to point on the surface.

15. (a, b)

The electric field is uniform and no charge is enclosed within the Gaussian surfaces, hence the net flux enclosed with each cylindrical midsection will be zero.

As the magnitude of the flux is proportional to number of electric field line. The number of electric field lines passing through the circular base of the cylindrical midsection is equal to the number of lines passing through caps which are the same.

DPP 2.2

Subjective Type

1. At all points where there is an electric field, it is radially outward. For each part of the problem, use a Gaussian surface in the form of a sphere that is concentric with the sphere of charge and passes through the point where the electric field is to be found. The field is uniform on the surface, so $\oint \vec{E} \cdot d\vec{A} = 4\pi r^2 E$, where r is the radius of the Gaussian surface.

For $r < a$, the charge enclosed by the Gaussian surface is $q_1(r/a)^3$. Gauss law yields

$$4\pi r^2 E = \left(\frac{q_1}{\epsilon_0}\right) \left(\frac{r}{a}\right)^3 \Rightarrow E = \frac{q_1 r}{4\pi\epsilon_0 a^3}$$

- (a) For $r = 0$, the above equation implies $E = 0$
(b) For $r = a/2$, we have

$$E = \frac{q_1(a/2)}{4\pi\epsilon_0 a^3} = \frac{(9 \times 10^9 \text{ N} \cdot \text{m}^2/\text{C}^2)(5.00)}{2(2.00 \times 10^{-2} \text{ m})^2} = 5.6 \times 10^{13} \text{ N/C}$$

- (c) For $r = a$, we have

$$E = \frac{q_1}{4\pi\epsilon_0 a^2} = \frac{(9 \times 10^9 \text{ N} \cdot \text{m}^2)(5.00 \text{ C})}{(2.00 \times 10^{-2} \text{ m})^2} = 1.1 \times 10^{14} \text{ N/C}$$

In the case where $a < r < b$, the charge enclosed by the Gaussian surface is q_1 so Gauss's law leads to

$$4\pi r^2 E = \frac{q_1}{\epsilon_0} \Rightarrow E = \frac{q_1}{4\pi\epsilon_0 r^2}$$

- (d) For $r = 1.50a$, we have

$$E = \frac{q_1}{4\pi\epsilon_0 r^2} = \frac{(9 \times 10^9 \text{ N} \cdot \text{m}^2/\text{C}^2)(5.00 \text{ C})}{(1.50 \times 2.00 \times 10^{-2} \text{ m})^2} = 5 \times 10^{13} \text{ N/C}$$

- (e) In the region $b < r < c$, since the shell is conducting, the electric field is zero. Thus, for $r = 2.30a$, we have $E = 0$.
(f) For $r > c$, the charge enclosed by the Gaussian surface is zero. Gauss's law yields $4\pi r^2 E \Rightarrow E = 0$. Thus, $E = 0$ at $r = 3.50a$.
(g) Consider a Gaussian surface that lies completely within the conducting shell. Since the electric field is zero everywhere on the surface, $\oint \vec{E} \cdot d\vec{A} = 0$ and, according to Gauss's law, the net charge enclosed by the surface is zero. If Q_i is the charge on the inner surface of the shell, then $q_1 + Q_i = 0$ and $Q_i = -q_1 = -5.00 \text{ C}$.
(h) Let Q_0 be the charge on the outer surface of the shell. Since the net charge on the shell is $-q$, $Q_i + Q_0 = -q_1$. This means $Q_0 = -q_1 - Q_i = -q_1 - (-q_1) = 0$.

2. (a) The cube is totally within the spherical volume, so the charge enclosed is

$$q_{\text{enc}} = \rho V_{\text{cube}} = (500 \times 10^{-9} \text{ C/m}^3)(0.0400 \text{ m})^3 = 3.20 \times 10^{-11} \text{ C}$$

By Gauss's law, we find $\Phi = q_{\text{enc}}/\epsilon_0 = 3.62 \text{ N.m}^2/\text{C}$

- (b) Now the sphere is totally contained within the cube (note that the radius of the sphere is less than half the side-length of the cube). Thus, the total charge is

$$q_{\text{enc}} = \rho V_{\text{sphere}} = 4.5 \times 10^{-10} \text{ C}$$

By Gauss's law, we find

$$\Phi = q_{\text{enc}}/\epsilon_0 = 51.1 \text{ N.m}^2/\text{C}$$

3. $\Phi_0 = 10^3 \text{ N.m}^2/\text{C}$. The net flux through the entire surface of the dice is given by

$$\begin{aligned} \Phi &= \sum_{n=1}^6 \Phi_n = \sum_{n=1}^6 (-1)^n n \Phi_0 \\ &= \Phi_0(-1 + 2 - 3 + 4 - 5 + 6) = 3\Phi_0 \end{aligned}$$

Thus, the net charge enclosed is

$$\begin{aligned} q &= \epsilon_0 \Phi = 3\epsilon_0 \Phi_0 = 3(8.85 \times 10^{-12} \text{ C}^2/\text{N} \cdot \text{m}^2) \\ &\quad (10^3 \text{ N} \cdot \text{m}^2/\text{C}) = 2.66 \times 10^{-8} \text{ C} \end{aligned}$$

Single Correct Answer Type

4. (b) Electric field at any point on Gaussian surface is due to all charges.

5. (b) Flux linked with the given sphere $\phi = \frac{Q}{\epsilon_0}$,

where Q = Charge enclosed by the sphere.

Hence $Q = \phi \epsilon_0 = (EA)\epsilon_0$

$$\Rightarrow Q = 4\pi(\gamma_0)^2 \times A\gamma_0\epsilon_0 = 4\pi\epsilon_0 A\gamma_0^3$$

6. (c) To apply Gauss's theorem it is essential that charge should be placed inside a closed surface. So imagine another similar cylindrical vessel above it as shown in the figure (dotted).



7. (b) Charge enclosed by cylindrical surface (length 100 cm) is

$$Q_{\text{enc}} = 100Q. \text{ By applying Gauss's law, } \phi = \frac{1}{\epsilon_0}(Q_{\text{enc}}) = \frac{1}{\epsilon_0}(100Q)$$

8. (b) For $r \leq R$: $\phi = EA\pi r^2 \Rightarrow \frac{\phi_0 r^2}{R^3} = E4\pi r^2$

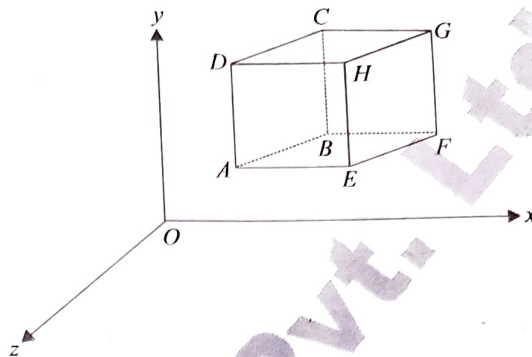
$$\Rightarrow E = \frac{\phi_0}{4\pi R^3}$$

$$\text{For } r > R: \phi_0 = E4\pi r^2 \Rightarrow E = \frac{\phi_0}{4\pi r^2}$$

9. (b) Field at face $ABCD = E_0 x_0 \hat{i}$

$$\text{Flux over the face } ABCD = E_0 x_0 \hat{i} \cdot a^2$$

The negative sign arises as the field is directed into the cube.



$$\text{Field at face } EFGH = E_0(x_0 + a)\hat{i}$$

$$\text{Flux over the face } EFGH = E_0(x_0 + a)a^2$$

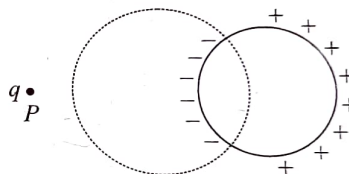
Flux over the other four faces is zero as the field is parallel to the surfaces.

$$\text{Total flux over the cube} = E_0 a^3 = \frac{1}{\epsilon_0} q$$

where q is the total charge under the cube

$$\therefore q = \epsilon_0 E_0 a^3$$

10. (c) Negative charge will be induced on the part of sphere inside the closed surface.



Net charge inside the closed surface is negative, hence flux is negative.

Multiple Correct Answers Type

11. (a, b, c, d)

- (a) Q lies outside Gaussian surface.
 (b) Net charge enclosed by Gaussian surface is zero.
 (c) As the charge is displaced towards sphere amount of negative charge induced on right half of sphere will increase, hence net flux through right hemispherical closed Gaussian surface increases.
 (d) Same reason as (c) and hence charge distribution on outer surface of sphere will change.

12. (a, c)

$$\phi_1 = E_1 2\pi r_1^2 \Rightarrow \phi_2 = E_2 2\pi r_2^2$$

$$E_1 \neq E_2$$

$$\frac{\phi_1 E_1 r_1^2}{\phi_2 E_2 r_2^2}$$

(i)

$$\text{But } \phi_1 = \frac{q_0}{2\epsilon_0}; \phi_2 = \frac{q_0}{2\epsilon_0} \Rightarrow \frac{\phi_1}{\phi_2} = 1$$

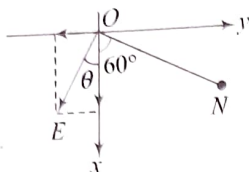
$$\text{From equation (i), } E_1 r_1^2 = E_2 r_2^2$$

$$\frac{r_1}{\sqrt{E_2}} = \frac{r_2}{\sqrt{E_1}}$$

Comprehension Type

13. (c) 14. (d) 15. (a)

The direction of electric field is in x - y plane as shown in the figure.



The magnitude of electric field is

$$E = \sqrt{E_x^2 + E_y^2} = \sqrt{3+1} = 2 \text{ V/m}$$

The direction of electric field is given by

$$\theta = \tan^{-1}$$

$$\frac{E_y}{E_x} = \tan^{-1} \frac{1}{\sqrt{3}} = 30^\circ$$

Hence electric field is normal to square frame $LMNO$ as shown in figure.

$$\therefore \text{electric flux} = \vec{E} \cdot \vec{A} = EA \cos 0 = 2 \times 1 = 2 \text{ V/m}$$

Since flux is maximum at $\theta = 60^\circ$, rotation by 30° either way would lead to decrease in flux.

$\therefore$ (d) is correct option for Q. 14.

Line ON and NM are both normal to uniform electric field. Hence work done by electric field as a point charge $1 \mu\text{C}$ is taken from O to M is zero.

$\therefore$ (a) is correct option of Q. 15.

DPP 2.3

Subjective Type

1. In the region between sheets 1 and 2, the net field is $E_1 - E_2 + E_3 = 2.0 \times 10^3 \text{ N/C}$. In the region between sheets 2 and 3, the net field is at its greatest value:

$$E_1 + E_2 + E_3 = 6.0 \times 10^5 \text{ N/C}$$

The net field vanishes in the region to the right of sheet 3, where $E_1 + E_2 = E_3$. We note the implication that σ_3 is negative (and is the largest surface-density, in magnitude). These three conditions are sufficient for finding the fields:

$$E_1 = 1.0 \times 10^5 \text{ N/C}, E_2 = 2.0 \times 10^5 \text{ N/C}, \text{ and}$$

$$E_3 = 3.0 \times 10^5 \text{ N/C}$$

Incorporating the values of E , we get

$$\frac{|\sigma_3|}{|\sigma_2|} = \frac{3.0 \times 10^5 \text{ N/C}}{2.0 \times 10^5 \text{ N/C}} = 1.5.$$

Recalling our observation, above, about σ_3 , we conclude that

$$\frac{\sigma_3}{\sigma_2} = -1.5.$$

2. The field due to the sheet is $E = \frac{\sigma}{2\epsilon_0}$. The force (in magnitude) on the electron (due to that field) is $F = eE$, and assuming it is the only force then the acceleration is

$$a = \frac{e\sigma}{2\epsilon_0 m} = \frac{v_s}{t_0} = \text{slope of the graph.}$$

$$\Rightarrow \sigma = \frac{2\epsilon_0 m v_s}{e t_0}$$

3. Let E_A designate the magnitude of the field at $r = 2.5 \text{ cm}$. Thus $E_A = 2.0 \times 10^7 \text{ N/C}$ and is totally due to the particle.

Since $E_{\text{particle}} = \frac{q}{4\pi\epsilon_0 r^2}$, then the field due to the particle at any

other point will relate to E_A by a ratio of distances squared.

Now, we note that at $r = 3.0 \text{ cm}$, the total contribution (from particle and shell) is $8.0 \times 10^7 \text{ N/C}$. Therefore,

$$E_{\text{shell}} + E_{\text{particle}} = E_{\text{shell}} + \left(2 \times \frac{4}{3}\right)^2 E_A = 8.0 \times 10^7 \text{ N/C}$$

Using the value for E_A noted above, we find $E_{\text{shell}} = 6.6 \times 10^7 \text{ N/C}$. Thus, with $r = 0.030 \text{ m}$, we find the charge Q using

$$E_{\text{shell}} = \frac{Q}{4\pi\epsilon_0 r^2}$$

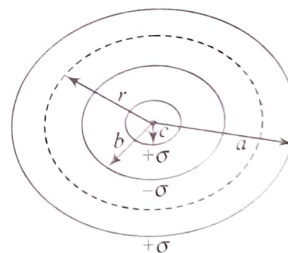
$$Q = 4\pi\epsilon_0 r^2 E_{\text{shell}}$$

$$= \frac{r^2 E_{\text{shell}}}{k} = \frac{(0.030 \text{ m})^2 (6.6 \times 10^7 \text{ N/C})}{9 \times 10^9 \text{ N} \cdot \text{m}^2/\text{C}^2} = 6.6 \times 10^{-6} \text{ C}$$

Single Correct Answer Type

4. (c) F_1 is zero as charge lies inside the shell (Electric field inside the shell due to its own charge is zero). $F_2 = F_3$ as charge over the surface of the shell behaves like centered at the centre.

5. (b)

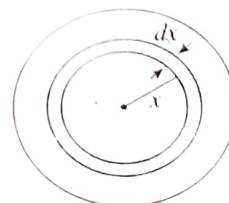


Electric field at a distance r ($a > r > b$) will be due to charges enclosed in r only, and since a sphere acts as a point charge for points outside its surface,

$$\therefore E = \frac{kQ_c}{r^2} + \frac{kQ_b}{r^2} = \frac{k}{r^2} (\sigma \times 4\pi c^2 + (-\sigma)4\pi b^2)$$

$$= \frac{\sigma}{\epsilon_0 r^2} (c^2 - b^2)$$

6. (a) We can consider all the charge inside the sphere to be concentrated on the center of sphere. Consider an elementary shell of radius x and thickness dx .



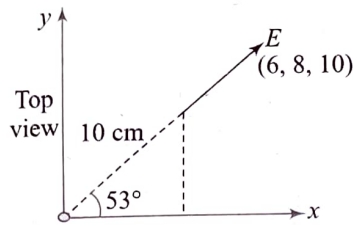
$$E = \frac{K \int dq}{r^2} = \frac{K \int 4\pi x^2 dx (\alpha x)}{r^2} = \frac{\alpha r^3}{4\epsilon_0}$$

7. (c) By Gauss's law, enclosed charge for points A and C will be zero, hence $E_A = E_C = 0$.

$$8. (d) E = \frac{\lambda}{2\pi\epsilon_0 d} = \frac{2K\lambda}{d}$$

$$= \frac{2 \times 9 \times 10^9 \times (10/9) \times 10^{-9}}{10 \times 10^{-2}} = 200 \text{ V/m}$$

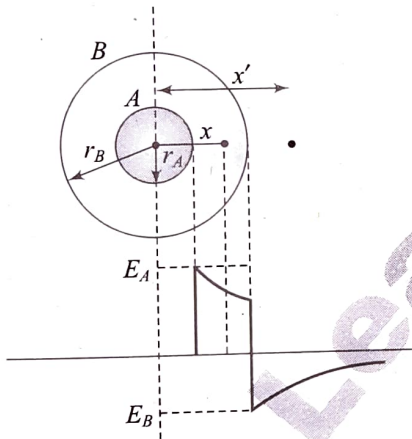
As field is radial out, there is no component of it in z-direction.



$$\vec{E} = (200 \cos 53^\circ \hat{i} + 200 \sin 53^\circ \hat{j}) \text{ V/m}$$

$$= \left(200 \times \frac{3}{5} \hat{i} + 200 \times \frac{4}{5} \hat{j} \right) = (120\hat{i} + 160\hat{j}) \text{ V/m}$$

9. (a) Inside the shell A, electric field $E_{in} = 0$



At the surface of shell A,

$$E_A = \frac{kQ_A}{r_A^2} \rightarrow (\text{a fixed positive value})$$

Between the shell A and B, at a distance x from the common centre

$$E = \frac{k \cdot Q_A}{x^2} \rightarrow (\text{as } x \text{ increases } E \text{ decreases})$$

At the surface of shell B,

$$E_B = \frac{k \cdot (Q_A - Q_B)}{r_B^2} \rightarrow (\text{a fixed negative value because } |Q_A| < |Q_B|)$$

Outside the both shell, at a distance x from the common centre

$$E_{out} = \frac{k(Q_A - Q_B)}{x^2} \rightarrow (\text{as } x' \text{ increases negative value of } E_{out} \text{ decreases and it becomes zero at } x = \infty)$$

$$10. (a) E_I = -\frac{2Q}{2A\epsilon_0} + \frac{Q}{2A\epsilon_0} = -\frac{Q}{2A\epsilon_0}$$

$$E_{II} = \frac{2Q}{2A\epsilon_0} + \frac{Q}{2A\epsilon_0} = \frac{3Q}{2A\epsilon_0}$$

$$E_{III} = \frac{2Q}{2A\epsilon_0} - \frac{Q}{2A\epsilon_0} = \frac{Q}{2A\epsilon_0}$$

Electric field in region I is towards left, but magnitude in region I and III is the same.

11. (a) Electric field on surface of a uniformly charged sphere is given

$$\text{by } \frac{Q}{4\pi\epsilon_0 R^2} = \frac{\rho R}{3\epsilon_0}$$

$$\text{Electric field at outside point is given by } E = \frac{Q}{4\pi\epsilon_0 r^2} = \frac{\rho R^3}{3\epsilon_0 r^2}$$

$$E_B = E_{\text{whole sphere}} - E_{\text{cavity}}$$

$$E_B = \frac{\rho r_0}{3\epsilon_0} - \frac{\rho \left(\frac{r_0}{2}\right)^3}{3\epsilon_0 \left(\frac{3r_0}{2}\right)^2} = \frac{17\rho r_0}{54\epsilon_0}$$

12. (a) We know that if a point charge subtends a half-angle α on the circular cross-section of a disc, then flux passing through the disc is:

$$\phi = \frac{q}{2\epsilon_0} (1 - \cos \alpha)$$

Also, if a point charge q lies on the axis of a charged disc of charge density σ and subtends a half-angle α , then it experiences a force

$$F = \frac{q\sigma}{2\epsilon_0} (1 - \cos \alpha) = \sigma\phi$$

13. (a) Applying equation, we have

$$E_1 = \frac{|q|}{4\pi\epsilon_0 R^3} r_1 = \frac{|q_1|}{4\pi\epsilon_0 R^3} \left(\frac{R}{2}\right) = \frac{1}{2} \frac{|q_1|}{4\pi\epsilon_0 R^2}$$

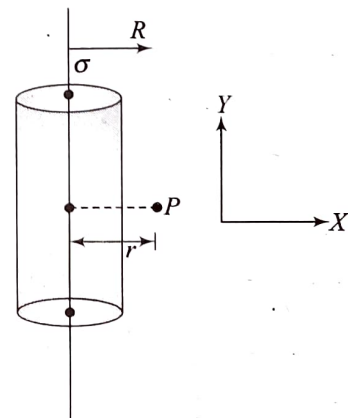
Also, outside sphere 2 we have

$$E_2 = \frac{|q_2|}{4\pi\epsilon_0 r^2} = \frac{|q_2|}{4\pi\epsilon_0 (1.50R)^2}$$

Equating these and solving for the ratio of charges, we arrive

$$\text{at } \frac{q_2}{q_1} = \frac{9}{8} = 1.125$$

14. (d) $\vec{E}$ at P would be due to two charge configurations, one due to linear charge and other due to charge on cylinder.



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$$\begin{aligned}\vec{E} &= \vec{E}_1 + \vec{E}_2 \\ &= \frac{\lambda}{2\pi\epsilon_0 r} \hat{i} + \frac{\sigma R}{\epsilon_0 r} \hat{i}\end{aligned}$$

[using Gauss's law, we can find $\vec{E}_2$]

For $\vec{E}$ to be zero,

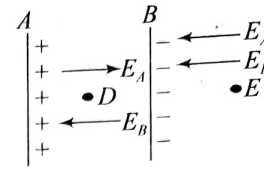
$$\begin{aligned}\frac{\lambda}{2\pi\epsilon_0 r} &= -\frac{\sigma R}{\epsilon_0 R} \\ \lambda &= -2\pi\sigma R\end{aligned}$$

Multiple Correct Answers Type

15. (b, d)

At E, $E_E = E_A - E_B$

$$= \frac{2/\pi \times 10^{-9}}{2 \cdot \epsilon_0} - \frac{1/\pi \times 10^{-9}}{2 \cdot \epsilon_0} = 18, \text{ towards right.}$$



At D,

$$E_O = E_A + E_B = \frac{(2/\pi) \times 10^{-9}}{2\epsilon_0} + \frac{(1/\pi) \times 10^{-9}}{2\epsilon_0} = 54,$$

towards right.

CHAPTER 3

DPP 3.1

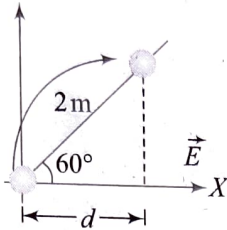
Single Correct Answer Type

1. (d) $W = qV = qE \cdot d$

$$\Rightarrow 4 = 0.2 \times E \times (2 \cos 60^\circ)$$

$$= 0.2 E \times (2 \times 0.5)$$

$$\therefore E = \frac{4}{0.2} = 20 \text{ NC}^{-1}$$



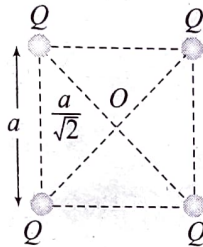
2. (c) Potential at centre O of the square

$$V_O = 4 \left(\frac{Q}{4\pi\epsilon_0 (a/\sqrt{2})} \right)$$

Work done in shifting $(-Q)$ charge from centre to infinity

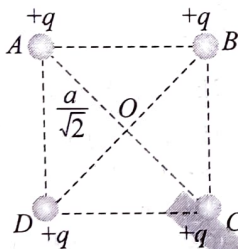
$$W = -Q(V_\infty - V_O) = QV_O$$

$$= \frac{4\sqrt{2}Q^2}{4\pi\epsilon_0 a} = \frac{\sqrt{2}Q^2}{\pi\epsilon_0 a}$$



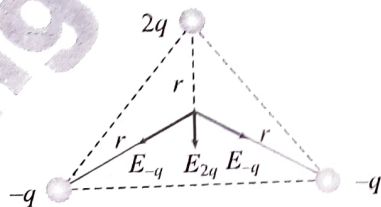
3. (b) Potential at the centre O , $V = 4 \times \frac{1}{4\pi\epsilon_0} \cdot \frac{Q}{a/\sqrt{2}}$

where $Q = \frac{10}{3} \times 10^{-9} \text{ C}$ and $a = 8 \text{ cm} = 8 \times 10^{-2} \text{ m}$



$$\text{So } V = 5 \times 9 \times 10^9 \times \frac{\frac{10}{3} \times 10^{-9}}{8 \times 10^{-2} \sqrt{2}} = 1500\sqrt{2} \text{ volt}$$

4. (b) Obviously, from charge configuration, at the centre electric field is non-zero. Potential at the centre due to $2q$ charge, $V_{2q} = \frac{2q}{r}$

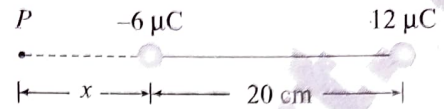


and potential due to $-q$ charge

$$V_{-q} = -\frac{q}{r} \quad (r = \text{distance of centre point})$$

$$\therefore \text{Total potential } V = V_{2q} + V_{-q} + V_{-q} = 0$$

5. (c) Point P will lie near the charge which is smaller in magnitude, i.e., $-6 \mu\text{C}$. Hence potential at P ,



$$V = \frac{1}{4\pi\epsilon_0} \frac{(-6 \times 10^{-6})}{x} + \frac{1}{4\pi\epsilon_0} \frac{(12 \times 10^{-6})}{(0.2 + x)} = 0 \Rightarrow x = 0.2 \text{ m}$$

6. (d) If charge acquired by the smaller sphere is Q , then its potential

$$120 = \frac{kQ}{2} \quad (i)$$

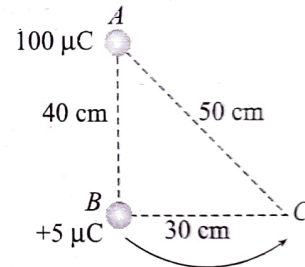
Also potential of the outer sphere

$$V = \frac{kQ}{6} \quad (ii)$$

From equation (i) and (ii) $V = 40 \text{ V}$

7. (d) Work done in displacing charge of $5 \mu\text{C}$ from B to C is

$$W = 5 \times 10^{-6} (V_C - V_B)$$



where

$$V_B = 9 \times 10^9 \times \frac{100 \times 10^{-6}}{0.4} = \frac{9}{4} \times 10^6 \text{ V}$$

$$\text{and } V_C = 9 \times 10^9 \times \frac{100 \times 10^{-6}}{0.5} = \frac{9}{5} \times 10^6 \text{ V}$$

$$\text{So } W = 5 \times 10^{-6} \times \left(\frac{9}{5} \times 10^6 - \frac{9}{4} \times 10^6 \right) = -\frac{9}{4} \text{ J}$$

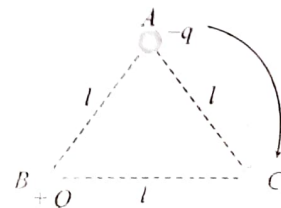
8. (a) Work done $W = 3 \times 10^{-6} (V_A - V_B)$, where

$$V_A = 10^{10} \left[\frac{(-5 \times 10^{-6})}{15 \times 10^{-2}} + \frac{2 \times 10^{-6}}{5 \times 10^{-2}} \right] = \frac{1}{15} \times 10^6 \text{ volt}$$

$$\text{and } V_B = 10^{10} \left[\frac{(2 \times 10^{-6})}{15 \times 10^{-2}} - \frac{5 \times 10^{-6}}{5 \times 10^{-2}} \right] = -\frac{13}{15} \times 10^6 \text{ volt}$$

$$\therefore W = 3 \times 10^{-6} \left[\frac{1}{15} \times 10^6 - \left(-\frac{13}{15} \times 10^6 \right) \right] = 2.8 \text{ J}$$

9. (d) According to figure, potential at A and C is equal. Hence work done in moving $-q$ charge from A to C is zero.



10. (b) Total potential at the centre $V = \frac{6q}{4\pi\epsilon_0 r}$

Required work done $= q \cdot V = \frac{6q^2}{4\pi\epsilon_0 r}$

11. (d) Work done on 2 coulomb charge $= \int q \vec{E} \cdot d\vec{r} = q \int_1^3 E dr$

$[\Theta r \text{ for } (1, 1, 0) = \sqrt{2} \text{ and } r \text{ for } (3, 0, 0) = 3]$

$= 2 \times \text{area of } E-r \text{ graph from } r = \sqrt{2} \text{ m to } r = 3$

$= 2 \times \left[\frac{1}{2} (3 - \sqrt{2}) 20 \right] = 20(3 - \sqrt{2}) \text{ J}$

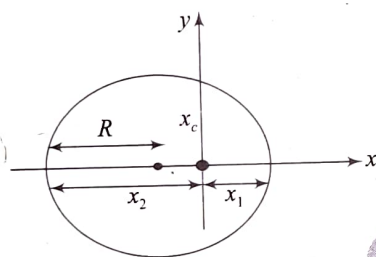
Comprehension Based

12. (c) 13. (c) 14. (b)

On the positive side of x-axis, potential is zero at distance x_1 (it is between both charges), then

$$\frac{k \cdot 6e}{r} = \frac{k \cdot 10e}{8-r} \Rightarrow r = 3 \text{ nm}$$

For the left side $\frac{k \cdot 6e}{x_2} = \frac{k \cdot 10e}{8+x_2} \Rightarrow x_2 = 12 \text{ nm}$



$$R = \frac{x_1 + x_2}{2} = 7.5 \text{ nm}$$

$$|x_c| = x_2 - R = 4.5 \text{ nm}$$

$$V_c = \frac{k \cdot 6e}{4.5 \times 10^{-9}} - \frac{k \cdot 10e}{12.5 \times 10^{-9}}$$

$$= 1.44 \times \frac{8}{15} = 0.77 \text{ V}$$

DPP 3.2

Subjective Type

- In the remaining three quadrants, put three more quarter sheets to convert this given arrangement to that of infinite sheet. Now contribution from all the four quarters to the z-component will be the same. Hence due to a quarter E_z at point $(0, 0, z)$ will be

$$\hat{E} = \frac{1}{4} \left(\frac{\sigma}{2\epsilon_0} \right) \frac{|z|}{z} \hat{k} = \frac{\sigma}{8\epsilon_0} \frac{|z|}{z} \hat{k}$$

Hence potential difference between points $(0, 0, d)$ and $(0, 0, 2d)$ will be

$$V_{2d} - V_d = - \int_d^{2d} \vec{E} \cdot d\vec{\ell} = - \int_d^{2d} E dz = - \int_d^{2d} \frac{\sigma}{8\epsilon_0} \frac{|z|}{z} dz$$

$$V_{2d} - V_d = - \int_d^{2d} \frac{\sigma}{8\epsilon_0} \frac{|z|}{z} \hat{k} \cdot d\vec{\ell} = - \frac{\sigma}{8\epsilon_0} \int_d^{2d} \frac{|z|}{z} dz = - \frac{\sigma}{8\epsilon_0} \ln 2$$

Single Correct Answer Type

2. (a) The electric potential $V(x, y, z) = 4x^2$ volt

$$\text{Now } \vec{E} = - \left(\hat{i} \frac{\partial V}{\partial x} + \hat{j} \frac{\partial V}{\partial y} + \hat{k} \frac{\partial V}{\partial z} \right)$$

$$\text{Now } \frac{\partial V}{\partial x} = 8x, \frac{\partial V}{\partial y} = 0 \text{ and } \frac{\partial V}{\partial z} = 0$$

Hence $\vec{E} = -8x\hat{i}$, so at point $(1 \text{ m}, 0, 2 \text{ m})$

$\vec{E} = -8\hat{i}$ volt/metre or 8 along negative X-axis.

3. (d) $E_x = -\frac{dV}{dx} = -(6 - 8y^2)$, $E_y = -\frac{dV}{dy} = -(16xy - 8 + 6z)$

$$E_z = -\frac{dV}{dz} = -(6y - 8z)$$

At origin $x = y = z = 0$ so, $E_x = -6$, $E_y = 8$ and $E_z = 0$

$$\Rightarrow E = \sqrt{E_x^2 + E_y^2} = 10 \text{ N/C}$$

Hence force $F = QE = 2 \times 10 = 20 \text{ N}$

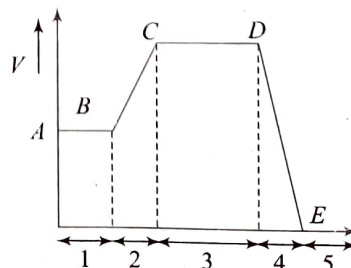
4. (d) Outside the charged sphere (for equal distances from centre) if electric fields at two points are the same, then both points must be equipotential points.

5. (d) $E_x = -\frac{dV}{dx} = -(-5) = 5$; $E_y = -\frac{dV}{dy} = -3$

$$\text{and } E_z = -\frac{dV}{dz} = -\sqrt{15}$$

$$E_{\text{net}} = \sqrt{E_x^2 + E_y^2 + E_z^2} = \sqrt{(5)^2 + (-3)^2 + (-\sqrt{15})^2} = 7$$

6. (b) Electric field in the regions 1, 3 and 5 is zero, i.e., $E_1 = E_3 = E_5$
Slope of the line BC < Slope of the line DE
i.e., $E_2 < E_4$



7. (d) The surface of the conductor is an equipotential surface since there is free flow of electrons within the conductor. Thus potential at Q is the same as that at P . That is $V_P = V_Q = V$. The electric field E at a point on the equipotential surface of the conductor is inversely proportional to the square of the radius of curvature r at that point. That is $E \propto r^{-2}$.

Since point Q has a larger radius of curvature than that at point P , the electric field at Q is less than that at P . That is $E_Q < E_P = E$.

8. (c) In this problem, the electric field intensity E and electric potential V are related as $E = -\frac{dV}{dr}$.

Electric field intensity $E = 0$ suggest that $\frac{dV}{dr} = 0$. This imply that $V = \text{constant}$.

Thus, $E = 0$ inside the charged conducting sphere causes the same electrostatic potential 100 V at any point inside the sphere.

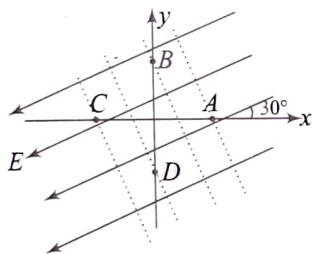
9. (b) $A = (0, 0)$, $B = (x_0, 0)$

$$= \int_A^B \vec{E} \cdot d\vec{n} = V_A - V_B = 0 - V_B$$

$$E_0 X_0 = -V_B$$

$$V_B = -E_0 X_0$$

10. (b) Four lines perpendicular to lines of electric field and passing through A, B, C and D are drawn. These are equipotential lines. As potential decreases in the direction of electric field, therefore $V_A > V_B > V_D > V_C$.



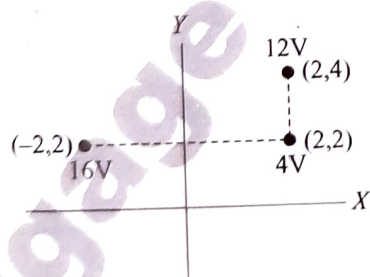
11. (a) $dV = -\vec{E} \cdot d\vec{r}$

$$= -(y\hat{i} + x\hat{j}) \cdot (dx\hat{i} + dy\hat{j})$$

$$= -(ydx + xdy) = -d(xy)$$

Integrating, we get $V = -xy + \text{constant}$.

12. (d)



$$\vec{E}_x = \frac{16 - 4}{2} \hat{i} = 3\hat{i}$$

$$\vec{E}_y = -\frac{12 - 4}{2} \hat{j} = -4\hat{j}$$

$$\vec{E} = 3\hat{i} - 4\hat{j}$$

13. (c) We know,

$$-\int_{\infty}^0 \vec{E} \cdot d\vec{r} = V = \left[-\int_{\infty}^{a/\sqrt{2}} \vec{E} \cdot d\vec{r} \right] + \left[-\int_{a/\sqrt{2}}^0 (\vec{E} \cdot d\vec{r}) \right]$$

$$-\int_{\infty}^0 \vec{E} \cdot d\vec{r} = V_{\text{centre}} - V_{\infty} = V - 0$$

$$\text{But } V = \frac{4q\sqrt{2}}{4\pi\epsilon_0 a} = \frac{4\sqrt{2}Kq}{a}$$

$$\text{Given, } -\int_{a/\sqrt{2}}^0 (\vec{E} \cdot d\vec{r}) = \frac{Kq\sqrt{2}}{a}$$

$$\text{So } -\int_{\infty}^{a/\sqrt{2}} \vec{E} \cdot d\vec{r} = \frac{Kq4\sqrt{2}}{a} - \frac{Kq\sqrt{2}}{a} = \frac{3\sqrt{2}Kq}{a}$$

Multiple Correct Answers Type

14. (a, b, d)

$$0 \leq x \leq a; V_X = \left[-\int_0^x E_x dx \right] + V_{(0)} = 0 \quad (\text{as } E_x = 0)$$

$$x \geq a; V_X = -\int_a^x E_x dx + V_{(a)}$$

$$= \left[-\int_a^x \frac{\sigma}{\epsilon_0} dx \right] + V_{(a)} = -\frac{\sigma}{\epsilon_0} (x - a)$$

$$x \leq 0; V_X = -\int_0^x E_x dx + V_{(0)}$$

$$= -\left(-\frac{\sigma}{\epsilon_0} \cdot x \right) + V_{(0)} = \frac{\sigma}{\epsilon_0} \cdot x$$

15. (a, b, c, d)

(a) Inside a charged conductor $E = 0$ but $V \neq 0$

(b) At the midpoint of two and opposite charges separated by a distance, $V = 0$ but $E \neq 0$

(c) At equatorial line of a dipole $E \neq 0$ but only $V = 0$

(d) If $V = \text{constant} \neq 0$, E will be zero as $E = -\frac{dV}{dr}$

DPP 3.3

Subjective Type

1. The charges on two metal spheres, before coming in contact, are given by

$$Q_2 = \sigma \cdot 4\pi R^2$$

$$= 4(\sigma \cdot 4\pi R^2) = 4Q_1$$

Let the charges on two metal spheres, after coming in contact becomes Q'_1 and Q'_2 .

Now applying law of conservation of charges is given by

$$Q'_1 + Q'_2 = Q_1 + Q_2 = 5Q_1$$

$$= 5(\sigma \cdot 4\pi R^2)$$

After coming in contact, they acquire equal potentials. Therefore, we have

$$\frac{1}{4\pi\epsilon_0} \frac{Q'_1}{R} = \frac{1}{4\pi\epsilon_0} \frac{Q'_2}{R}$$

On solving we get,

$$\therefore Q'_1 = \frac{5}{3}(\sigma \cdot 4\pi R^2) \text{ and } Q'_2 = \frac{10}{3}(\sigma \cdot 4\pi R^2)$$

$$\therefore \sigma_1 = \frac{5}{3}\sigma \text{ and } \sigma_2 = \frac{5}{6}\sigma$$

2. Let any arbitrary point on the required plane is (x, y, z) . The two charges lies on z -axis at a separation of $2d$.

The potential at the point P due to two charges is given by

$$\frac{q_1}{\sqrt{x^2 + y^2 + (z-d)^2}} + \frac{q_2}{\sqrt{x^2 + y^2 + (z+d)^2}} = 0$$

$$\therefore \frac{q_1}{\sqrt{x^2 + y^2 + (z-d)^2}} = \frac{-q_2}{\sqrt{x^2 + y^2 + (z+d)^2}}$$

On squaring and simplifying we get,

$$x^2 + y^2 + z^2 + \left[\frac{(q_1/q_2)^2 + 1}{(q_1 - q_2) - 1} \right] (2zd) + d^2 = 0$$

This is the equation of a sphere with centre at

$$\left(0, 0, -2d \left[\frac{q_1^2 + q_2^2}{q_1^2 - q_2^2} \right] \right)$$

Note: The centre and radius of sphere $(x-a)^2 + (y-b)^2 + (z-c)^2 = r^2$ is (a, b, c) and r respectively.

Single Correct Answer Type

3. (a) In this problem, the collection of charges, whose total sum is not zero, with regard to great distance can be considered as a point charge. The equipotentials due to point charge are spherical in shape as electric potential due to point charge q is given by

$$V = k_e \frac{q}{r}$$

This suggest that electric potentials due to point charge is the same for all equidistant points. The locus of these equidistant points, which are at same potential, form spherical surface.

4. (c) The work done by a electrostatic force is given by $W_{12} = q(V_2 - V_1)$. Here initial and final potentials are the same in all three cases and same charge is moved, so work done is the same in all three cases.
5. (c) $ABCDE$ is an equipotential surface, on equipotential surface no work is done in shifting a charge from one place to another.

6. (c) Using $dV = -\vec{E} \cdot d\vec{r}$

$$\Rightarrow \Delta V = -E \cdot \Delta r \cos \theta$$

$$\Rightarrow E = \frac{-\Delta V}{\Delta r \cos \theta}$$

$$\Rightarrow E = \frac{-(20-10)}{10 \times 10^{-2} \cos 120^\circ}$$

$$= \frac{-10}{10 \times 10^{-2} (-\sin 30^\circ)} = \frac{-10^2}{-1/2} = 200 \text{ V/m}$$

Direction of E be perpendicular to the equipotential surface, i.e., at 120° with x -axis.

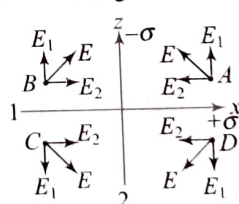
7. (b) Work done by the field $W = q(-dV) = -e(V_A - V_B)$

$$= e(V_B - V_A) = e(V_C - V_A) \quad (\because V_B = V_C)$$

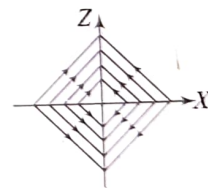
$$\Rightarrow (V_C - V_A) = \frac{W}{e} = \frac{6.4 \times 10^{-19}}{1.6 \times 10^{-19}} = 4 \text{ V}$$

8. (b) Electric lines of force do not enter a conductor. It means the boundary lines in the figure from where field lines starts should be the surface of the conductor. There should be positive charge present on the surface of this conductor. Potential of a conductor is constant but not necessarily zero.

9. (c) The electric field intensity due to each uniformly charged infinite plane is uniform. The electric field intensity at points A, B, C and D due to plane 1 and plane 2 and both planes are given by E_1, E_2 and E as shown in Figure 1. Hence the electric lines of forces are as given in Figure 2



(Figure 1)



(Figure 2)

Aliter:

Electric lines of forces originate from positively charged plane and terminate at negatively charged plane. Hence the correct representation of ELOF is as shown Figure 2.

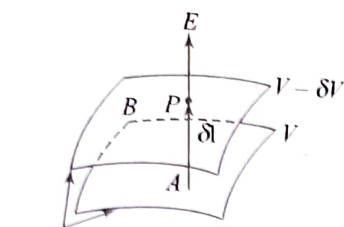
Multiple Correct Answers Type

10. (a, b, c)

The electric field intensity E is inversely proportional to the separation between equipotential surfaces. So, equipotential surfaces are closer in regions of large electric fields.

Since, the electric field intensities is large near sharp edges of charged conductor and near regions of large charge densities. Therefore, equipotential surfaces are closer at such places.

11. (b, c, d)



Equipotentials

Here, in the figure electric field is always remain in the direction in which the potential decreases steepest. Its magnitude is given by the change in the magnitude of potential per unit displacement normal to the equipotential surface at the point.

The electric field in z -direction suggests that equipotential surfaces are in x - y plane. Therefore, the potential is a constant for any x for a given z , for any y for a given z and on the x - y plane for a given z .

12. (b, c)

Potential inside a charged conductor is the same everywhere and equal in potential at the surface while outside the conductor it decreases with the distance. On the other hand, electric field is zero everywhere inside the charged conductor but nonzero outside. So, across the surface of a charged conductor, potential is continuous while electric field is discontinuous.

13. (b, c)

If the charge is given to a conducting sphere, then an electric field is established in the surrounding space. Magnitude of electric field is maximum just outside the sphere. This maximum electric field may be increased to the dielectric strength of the surrounding medium. Therefore, there is a limiting value of maximum charge, which can be given to the conducting sphere. Hence option (a) is wrong. Obviously, the conducting sphere cannot be charged to a potential greater than a certain value. Hence, option (b) is correct. It can be easily said that (c) is also correct.

14. (a, d)

If there is no external electric field, then the charge given to a conducting sphere gets uniformly distributed over its surface. Therefore, option (a) is correct.

If an external electric field exists, then the charge gets distributed over the surface of the sphere in such a way that the electric field inside the sphere can become equal to zero. Hence, distribution of the charge on the surface of sphere will be non-uniform. Therefore, (b) is correct. Obviously (c) is wrong.

Since electric field inside the conducting sphere is equal to zero, therefore, potential difference between two points in the sphere is equal to zero. It means the potential is the same at every point of the sphere. Therefore, (d) is correct.

True and False Type

15. (True)

Since the two spheres are at the same potential, therefore

$$\frac{kq_1}{R_1} = \frac{kq_2}{R_2} \Rightarrow \frac{kq_1 R_1}{4\pi R_1^2} = \frac{kq_2 R_2}{4\pi R_2^2}$$

$$\text{or } \sigma_1 R_1 = \sigma_2 R_2 \Rightarrow \frac{\sigma_1}{\sigma_2} = \frac{R_2}{R_1}$$

As $R_2 < R_1$; hence $\sigma_1 < \sigma_2$

The charge density of the smaller sphere is more than that of the larger one.

16. (False)

The free electrons experience electrostatic force in a direction opposite to the direction of electric field being of negative charge. The electric field is always directed from higher potential to lower travel.

Therefore, electrostatic force and hence direction of travel of electrons are from lower potential to region of higher potential.

17. (True)

For given charge the potential depends on the size and geometry of the conductor, so two adjacent conductors carrying the same charge of different dimensions may have different potentials.

18. (False)

As electric field is conservative, work done will be zero in both the cases.

19. (True)

Let's assume contradicting statement that the potential is not same inside the closed equipotential surface. Let the potential just inside the surface be different to that of the surface causing

a potential gradient $\left(\frac{dV}{dr}\right)$. Consequently electric field comes into existence, which is given by as $E = -\frac{dV}{dr}$.

Consequently field lines are pointing inwards or outwards from the surface. These lines cannot be again on the surface, as the surface is equipotential. It is possible only when the other end of the field lines are originated from the charges inside.

This contradict the original assumption. Hence, the entire volume inside must be equipotential.

20. (True)

Let us take any path from the charged conductor to the uncharged conductor along the direction of electric field. Therefore, the electric potential decreases along this path.

Now, another path from the uncharged conductor to infinity will again continually lower the potential further. This ensures that the uncharged body must be intermediate in potential between that of the charged body and that of infinity.

DPP 3.4

Subjective Type

1. Let the third charge $+q$ is slightly displaced from mean position towards the first charge. So, the total potential energy of the system is given by

$$U = \frac{1}{4\pi\epsilon_0} \left\{ \frac{-q^2}{(d-x)} + \frac{-q^2}{(d+x)} \right\}$$

$$U = \frac{-q^2}{4\pi\epsilon_0} \frac{2d}{(d^2 - x^2)}$$

$$\frac{dU}{dx} = \frac{-q^2 2d}{4\pi\epsilon_0} \cdot \frac{2x}{(d^2 - x^2)^2}$$

S.24 Electrostatics and Current Electricity

The system will be in equilibrium, if

$$F = -\frac{dU}{dx} = 0$$

On solving, $x = 0$. So for, $+q$ charge to be in stable/unstable equilibrium, finding second derivative of PE is as follows:

$$\begin{aligned}\frac{d^2U}{dx^2} &= \left(\frac{-2dq^2}{4\pi\epsilon_0} \right) \left[\frac{2}{(d^2 - x^2)^2} - \frac{8x^2}{(d^2 - x^2)^3} \right] \\ &= \left(\frac{-2dq^2}{4\pi\epsilon_0} \right) \frac{1}{(d^2 - x^2)^3} [2(d^2 - x^2)^2 - 8x^2]\end{aligned}$$

At $x = 0$

$$\frac{d^2U}{dx^2} = \left(\frac{-2dq^2}{4\pi\epsilon_0} \right) \left(\frac{1}{d^6} \right) (2d^2), \text{ which is } < 0$$

This shows that system will be unstable equilibrium.

Single Correct Answer Type

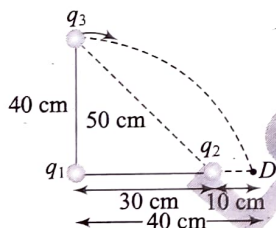
2. (c) The positively charged particle experiences electrostatic force along the direction of electric field. Thus, the work is done by the electric field on the positive charge, hence electrostatic potential energy of the positive charge decreases.

3. (d) Length of the diagonal of a cube having each side b is $\sqrt{3}b$. So distance of the centre of cube from each vertex is $\frac{\sqrt{3}b}{2}$.

Hence potential energy of the given system of charge is

$$U = 8 \times \left\{ \frac{1}{4\pi\epsilon_0} \cdot \frac{(-q)(q)}{\sqrt{3}b/2} \right\} = \frac{-4q^2}{\sqrt{3}\pi\epsilon_0 b}$$

4. (a) Change in potential energy ($\Delta U = U_f - U_i$)



$$\Rightarrow \Delta U = \frac{1}{4\pi\epsilon_0} \left[\left(\frac{q_1 q_3}{0.4} + \frac{q_2 q_3}{0.1} \right) - \left(\frac{q_1 q_3}{0.4} + \frac{q_2 q_3}{0.5} \right) \right]$$

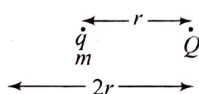
$$\Rightarrow \Delta U = \frac{1}{4\pi\epsilon_0} [8q_2 q_3] = \frac{q_3}{4\pi\epsilon_0} (8q_2)$$

$$\therefore k = 8q_2$$

5. (b) Applying conservation of energy, we get

$$\frac{KQq}{r} = \frac{KQq}{2r} + \frac{1}{2}mv^2$$

$$\frac{1}{2}mv^2 = \frac{KQq}{2r} \Rightarrow v = \sqrt{\frac{KQq}{mr}}$$



force required to keep Q fixed = Coulombic repulsion between the charges

= force on charge q

$\therefore$ Impulse = change in momentum of

$$q = mv = \sqrt{\frac{mkQq}{r}} = \sqrt{\frac{Qqm}{4\pi\epsilon_0 r}}$$

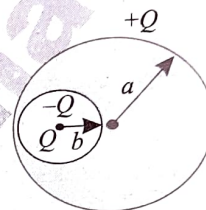
$$6. (b) (W_{AB}) \text{ electric force} = U_A - U_B = 0 - \frac{KQ^2}{2R} = \frac{-Q^2}{8\pi\epsilon_0 R}$$

[$\therefore U_A = 0$ as sphere is large]

$$7. (c) U = \frac{-kqQ}{a} + \frac{kqQ}{b} - \frac{kqQ}{b} + \frac{kq^2}{2a} + \frac{kq^2}{2b}$$

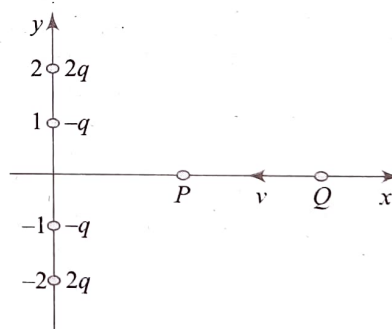
8. (a) $-Q$ and Q will be induced uniformly as shown.

Total energy = Self energy + interaction energy



$$\begin{aligned}&= \frac{K(-Q)^2}{2b} + \frac{K(Q)^2}{2a} + \frac{K(Q)(-Q)}{b} + \frac{K(Q)(+Q)}{a} + \frac{K(Q)(-Q)}{a} \\ &= KQ^2 \left(\frac{1}{2a} - \frac{1}{2b} \right)\end{aligned}$$

9. (b)



There exists a point P on the x -axis (other than the origin), where net electric field is zero. Once the charge Q reaches point P , attractive forces of the two $-ve$ charges will dominate and automatically cause the charge Q to cross the origin.

Now if Q is projected with just enough velocity to reach P , its KE at P is zero,

But while being attracted towards origin it acquires KE and hence its net energy at the origin is positive. (PE at origin = zero).

$$10. (c) U = \frac{Kq^2}{a} \left(-1 + 2 - \frac{2}{\sqrt{2}} \right)$$

$$= \frac{Kq^2}{a} (1 - \sqrt{2}) \Rightarrow U = -\frac{Kq^2}{a} (\sqrt{2} - 1)$$

$$11. (d) U_1 = \frac{3KQ^2}{a} \text{ where } a = \text{side of equilateral triangle}$$

$$U_1 = \frac{3kQ^2}{a} + \frac{3kQq}{a/\sqrt{3}} \text{ where } q \text{ is the charge brought at the center}$$

$$U_f = 0 \Rightarrow q = \frac{-Q}{\sqrt{3}}$$

12. (d)

If charge is being moved slowly, $\vec{F}_a = -\vec{F}_E$ $W_a + W_E = \Delta KE = 0$ [charge is moved slowly]

$$\Rightarrow W_a = -W_E \text{ also } W_E = -4U \text{ thus } W_a = +4U$$

As force F_a and displacement are 180° ,

$$\vec{F} \cdot d\vec{r} < 0 \text{ or } W_a < 0 \text{ thus } \Delta U < 0$$

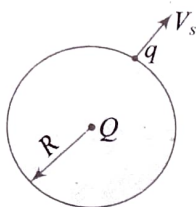
Therefore U decreases.

13. (c)

Let q be positive.

If it escapes, then from energy conservation principle,

$$\frac{1}{2}mv_s^2 + \frac{KQq}{R} = 0$$

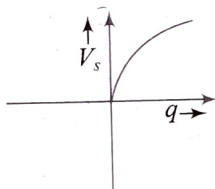


$$v = \sqrt{\frac{-2KQq}{Rm}} \text{ [Note that } Q \text{ is negative, therefore the quantity within the root is positive.]}$$

within the root is positive.}

$$\therefore v \propto \sqrt{q}$$

When q is negative, escape velocity will be zero due to electrostatic repulsion from negative Q .



Multiple Correct Answers Type

14. (b,d)

Since net force on negative charge is always directed towards fixed positive charge, the torque on negative charge about positive charge is zero. Therefore angular momentum of negative charge about fixed positive charge is conserved.

15. (a,d)

By conserving energy of the first ball,

$$0 + \frac{q^2}{4\pi\epsilon_0} \left[\frac{1}{r_{12}} + \frac{1}{r_{13}} + \frac{1}{r_{14}} + \dots + \frac{1}{r_{1N}} \right] = K_1 + 0$$

And for the second ball,

$$0 + \frac{q^2}{4\pi\epsilon_0} \left[\frac{1}{r_{23}} + \frac{1}{r_{24}} + \dots + \frac{1}{r_{2N}} \right] = K_2 + 0$$

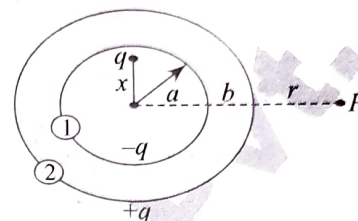
[It can be observed $K_1 > K_2$]

$$K = K_1 - K_2 = \frac{q^2}{4\pi\epsilon_0} \left(\frac{1}{d} \right) \Rightarrow q = \sqrt{4\pi\epsilon_0 d K}$$

DPP 3.5

Subjective Type

1. Net effect due to charge inside the cavity is zero for outside point.



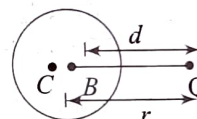
On S_1 surface $-q$ charge distributed non-uniformly and on S_2 surface $(Q+q)$ charge distributed uniformly.

$$E_p = \frac{K \cdot (Q+q)}{r^2}$$

$$V_p = \frac{K \cdot (Q+q)}{r}$$

$$V_c = \frac{Kq}{x} + \frac{K(-q)}{a} + \frac{K(Q+q)}{b}$$

2. Net potential at any point inside the conductor,



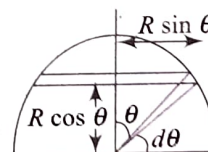
$$V = \frac{KQ}{r}$$

Potential at B = potential due to Q + potential due to induced charge

$$\frac{KQ}{r} = \frac{KQ}{d} + V_{in}$$

$$\therefore V_{in} = \frac{KQ}{r} - \frac{KQ}{d}$$

3. Electric potential:



$$V = \frac{KQ_{net}}{R} = \frac{1}{4\pi\epsilon_0} \times \frac{(2\pi R^2 \sigma)}{R}$$

$$V = \frac{R\sigma}{2\epsilon_0}$$

$$\text{Electric field: } dE = \frac{K(dq)(R \cos \theta)}{[(R \sin \theta)^2 + (R \cos \theta)^2]^{3/2}}$$

$$\text{Here, } dq = 2\pi(R \sin \theta) \cdot (R d\theta)$$

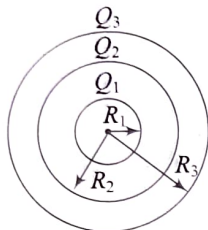
So,

$$dE = \frac{1}{4\pi\epsilon_0} \times \frac{2\pi R^2 \sigma \sin\theta \cdot d\theta \cdot R \cos\theta}{R^3}$$

$$\int dE = \frac{\sigma}{4\epsilon_0} \int_0^{\pi/2} \sin 2\theta \, d\theta$$

$$E = \frac{\sigma}{4\epsilon_0} \left[\frac{-\cos 2\theta}{2} \right]_0^{\pi/2} = \frac{\sigma}{4\epsilon_0}$$

4. Assume the radius and charge on the spheres as shown. After connection let us assume that the charge on the inner sphere is x , then on the outer sphere it will be $Q_1 + Q_2 - x$. Now their potential should be the same finally



Potential at surface of sphere of radius

$$R_1 = \frac{Kx}{R_1} + \frac{KQ_2}{R_2} + \frac{K(Q_1 + Q_3 - x)}{R_3}$$

Potential at surface of sphere of radius,

$$R_3 = \frac{Kx}{R_3} + \frac{KQ_2}{R_3} + \frac{K(Q_1 + Q_3 - x)}{R_3}$$

Because both the potential is the same

$$\therefore \frac{Kx}{R_1} + \frac{KQ_2}{R_2} + \frac{K(Q_1 + Q_3 - x)}{R_3} = \frac{Kx}{R_3} + \frac{KQ_2}{R_3} + \frac{K(Q_1 + Q_3 - x)}{R_3}$$

$$\text{or } \frac{Kx}{R_1} + \frac{KQ_2}{R_2} = \frac{Kx}{R_3} + \frac{KQ_2}{R_3}$$

From the equation it is clear that 'x' is independent of Q_3 .

5. Potential on the surface of the conducting sphere = potential at its center C. ($\because$ conductor is an equipotential body)

$$\text{Potential at C due to the ring} = \frac{kQ}{\sqrt{R^2 + l^2}} = \frac{kQ}{R\sqrt{10}}$$

$$\text{Potential at C due to charges on the spherical conductor} = \frac{kQ}{R}$$

$$\therefore \text{Potential of sphere} = \frac{kQ}{R\sqrt{10}} + \frac{kQ}{R}$$

No even if charge on the ring is not distributed uniformly, still potential at C due to it will have the same value.

6. Assume a solid sphere without cavity. Potential at A due to this solid sphere

$$= V'_A = \frac{3}{2} \cdot \frac{1}{4\pi\epsilon_0} \cdot \frac{\left(\frac{4}{3}\pi R^2 \rho\right)}{R} = \frac{\rho R^2}{2\epsilon_0}$$

$$\text{Electric field 'C' due to this} = \vec{E}'_C = \frac{\rho}{3\epsilon_0} \vec{AC}$$

Now consider the cavity filled with negative charge

$$V''_A = \frac{1}{4\pi\epsilon_0} \cdot \frac{\frac{4}{3}\pi \left(\frac{R}{2}\right)^3 (-\rho)}{\frac{R}{2}} = \frac{-\rho R^2}{12\epsilon_0}$$

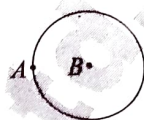
$$\vec{E}''_C = \frac{-\rho}{3\epsilon_0} \vec{BC}$$

Now net values for the solid sphere with the cavity can be given by superposition of the above two cases.

$$\text{Hence, } V_A = V'_A + V''_A = \frac{\rho R^2}{\epsilon_0} \left(\frac{1}{2} - \frac{1}{12} \right) = \frac{5\rho R^2}{12\epsilon_0}$$

$$\vec{E}_C = \vec{E}'_C + \vec{E}''_C = \frac{\rho}{3\epsilon_0} (\vec{AC} - \vec{BC}) = \frac{\rho}{3\epsilon_0} \vec{AB}$$

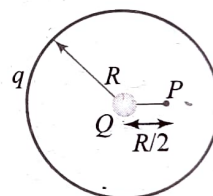
$$\therefore E_C = \frac{\rho}{3\epsilon_0} \left(\frac{R}{2} \right) = \frac{\rho R}{6\epsilon_0}$$



Single Correct Answer Type

7. (d) Electric potential at P

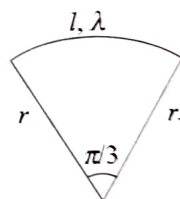
$$V = \frac{kQ}{R/2} + \frac{kq}{R} = \frac{2Q}{4\pi\epsilon_0 R} + \frac{q}{4\pi\epsilon_0 R}$$



8. (c) Length of the arc = $r\theta = \frac{r\pi}{3}$

$$\text{Charge on the arc} = \frac{r\pi}{3} \times \lambda$$

$$\therefore \text{Potential at center} = \frac{kq}{r} = \frac{1}{4\pi\epsilon_0} \times \frac{r\pi \lambda}{3r} = \frac{\lambda}{12\epsilon_0}$$



9. (b) $W = q(V_{O_2} - V_{O_1})$

$$\text{where } V_{O_1} = \frac{Q_1}{4\pi\epsilon_0 R} + \frac{Q_2}{4\pi\epsilon_0 R\sqrt{2}}$$

$$\text{and } V_{O_2} = \frac{Q_2}{4\pi\epsilon_0 R} + \frac{Q_1}{4\pi\epsilon_0 R\sqrt{2}}$$

$$\Rightarrow V_{O_2} - V_{O_1} = \frac{(Q_2 - Q_1)}{4\pi\epsilon_0 R} \left[1 - \frac{1}{\sqrt{2}} \right]$$

$$\text{So, } W = \frac{q \cdot (Q_2 - Q_1) (\sqrt{2} - 1)}{4\pi\epsilon_0 R \sqrt{2}}$$

10. (a) Let q_1 = charge on inner sphere

 q_2 = charge on outer sphere

C = common centre

$$\frac{kq_1}{a} + \frac{kq_2}{b} = 10, V_c = \frac{kq_1}{a} + \frac{kq_2}{b} = 10 \text{ volt}$$

$$11. (a) \quad V_C - V_S = \frac{3}{2} \frac{KQ}{R} - \frac{KQ}{R} \\ = \frac{KQ}{2R} = \frac{1}{8\pi\epsilon_0 R} \left(\frac{4}{3} \right) \pi R^3 \rho = \frac{R^2 \rho}{6\epsilon_0}$$

12. (c) Let the radius of each mercury drop be r .
If q is the charge on each drop
The potential of drop

$$V = \frac{q}{4\pi\epsilon_0 r} \quad \text{or } q = 4\pi\epsilon_0 r V \quad (1)$$

Let R be the radius of the new drop formed by combination of 1000 drops of radius r .

$$\frac{4\pi}{3} R^3 = 1000 \frac{4\pi}{3} r^3 \Rightarrow R = 10r \quad (2)$$

$$\therefore \text{Potential of new drop } \frac{(1000q)}{4\pi\epsilon_0 R} = \frac{(100q)}{4\pi\epsilon_0 r} = 100 \text{ V}$$

Comprehension Based

13. (b) 14. (c) 15. (a)

The inner sphere is grounded, hence its potential is zero. The net charge on isolated outer sphere is zero. Let the charge on inner sphere be q' .

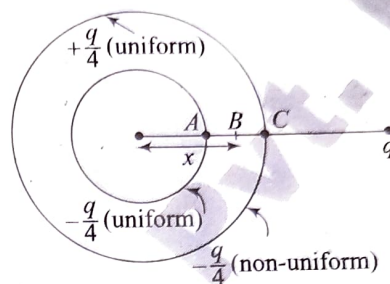
$\therefore$ Potential at centre of inner sphere is

$$= \frac{1}{4\pi\epsilon_0} \frac{q'}{a} + 0 + \frac{1}{4\pi\epsilon_0} \frac{q}{4a} = 0$$

$$\therefore q' = -\frac{q}{4}$$

The region in between conducting sphere and shell is shielded from charges on and outside the outer surface of shell. Hence charge distribution on the surface of sphere and inner surface of shell is uniform.

The distribution of induced charge on outer surface of shell depends only on point charge q , hence is nonuniform. The charge distribution on all surfaces is as shown.



The electric field at B is $= \frac{1}{4\pi\epsilon_0} \cdot \frac{q}{4x^2}$ towards left.

$$V_C = V_C - V_A = - \int_{2a}^a \frac{1}{4\pi\epsilon_0} \frac{q}{4x^2} dx = \frac{1}{32\pi\epsilon_0} \cdot \frac{q}{a}$$

CHAPTER 4

DPP 4.1

Subjective Type

$$1. E < 10^6 \Rightarrow \frac{10^3}{d} < 10^6$$

$$d > 10^{-3} \text{ m}^2 \Rightarrow C = \frac{k\epsilon_0 A}{d}$$

$$d = \frac{k\epsilon_0 A}{C} > 10^{-3}$$

$$A > \frac{10^{-3} \times C}{k\epsilon_0}$$

$$\Rightarrow A > \frac{10^{-3} \times 50 \times 10^{-12}}{(6\pi) \times \left(\frac{1}{36\pi} \times 10^{-9}\right)} = 300 \text{ mm}^2$$

2. Assuming the required final voltage be V . If C is the capacitance of the capacitor without the dielectric, then the charge on the capacitor is given by $Q_1 = CV$

Since the capacitor with the dielectric has a capacitance KC . Hence, the charge on the capacitor is given by

$$Q_2 = KCV = (2V)CV = 2CV^2$$

The initial charge on the capacitor is given by

$$Q_0 = CV_0$$

From the conservation of charges, $Q_0 = Q_1 + Q_2$

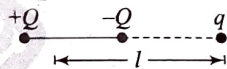
$$\text{or } CV_0 = CV + 2CV^2 \Rightarrow 2V^2 + V - V_0 = 0$$

$$V = \frac{-1 \pm \sqrt{1+8V_0}}{4}$$

On solving for $V_0 = 78$ volt, we get $V = 6$ volt

Single Correct Answer Type

3. (b) The two plates act as a dipole



Force on charge q , $F = Eq$

$$= \left(\frac{2kQd}{l^3} \right) \cdot q = \frac{Qqd}{2\pi\epsilon_0 l^3}$$

4. (c) Electric field between the plates of a parallel plate capacitor

$$E = \frac{\sigma}{\epsilon_0} = \frac{Q}{A\epsilon_0}, \text{ i.e., } E \propto d^0$$

5. (a) Potential difference across the condenser,

$$V = V_1 + V_2 = E_1 t_1 + E_2 t_2 = \frac{\sigma}{K_1 \epsilon_0} t_1 + \frac{\sigma}{K_2 \epsilon_0} t_2$$

$$\text{hence } V = \frac{Q}{A\epsilon_0} \left(\frac{t_1}{k_1} + \frac{t_2}{k_2} \right)$$

6. (a) Force on one plate due to another is

$$F = qE = q \times \frac{\sigma}{2\epsilon_0 K} = q \left(\frac{q}{2AK\epsilon_0} \right) = \frac{q^2}{2AK\epsilon_0}$$

(where $\frac{\sigma}{2\epsilon_0 K}$ is the electric field produced by one plate at the location of other).

7. (b) While drawing the dielectric plate outside, the capacitance decreases till the entire plate comes out and then becomes constant. So, V increases and then becomes constant.

8. (c) Battery is disconnected so Q will be constant as $C \propto K$. So with introduction of dielectric slab, capacitance will increase.

Using $Q = CV$, V will decrease, and using $U = \frac{Q^2}{2C}$, energy will decrease.

9. (b) When a dielectric K is introduced in a parallel plate condenser, its capacity becomes K times. Hence $C' = 5C_0$.

$$\text{Energy stored } W_0 = \frac{q^2}{2C_0}$$

$$\therefore W' = \frac{q^2}{2C'} = \frac{q^2}{2 \times 5C_0} \Rightarrow W' = \frac{W_0}{5}$$

10. (b) The energy density of parallel plate capacitor is given by

$$U = \frac{1}{2} \epsilon_0 E^2 = \frac{1}{2} \epsilon_0 \left(\frac{V}{d} \right)^2$$

$$= \frac{1}{2} \times 8.85 \times 10^{-12} \text{ C}^2/\text{Nm}^2 \times \left(\frac{300 \text{ volt}}{2 \times 10^{-3} \text{ m}} \right)^2 = 0.1 \text{ J/m}^3$$

11. (c) Energy density = $\frac{1}{2} k\epsilon_0 E^2$

Since the cell remains connected, V remains unchanged (and therefore E remains unchanged)

$\therefore$ Energy density will increase k times.

12. (c) As voltage applied across capacitor is the same, i.e., 10 V in both case. Therefore in both cases $Ed = 10 \Rightarrow E = \frac{10}{d}$, as d is constant. Therefore electric field remains the same as 10 V/m

13. (c) Charge on outer surface of $C = -$ charge on inner surface of C
Hence potential at B due to charge on a conductor $C = 0$
Charge on outer surface of dielectric = $-$ charge in inner surface of dielectric

$\therefore$ Potential at B due to charge on a dielectric = 0

$$\text{Potential at } B \text{ due to charge on } A = \frac{Q}{4\pi\epsilon_0 b}$$

$$\therefore \text{Net potential at } B = \frac{Q}{4\pi\epsilon_0 b}$$

Multiple Correct Answers Type

14. (a, c)

$$E_x = 3x^2 + 0.4 \text{ N/C}$$

$$V = \int E_x dx = \int_0^{0.2} (3x^2 + 0.4) dx = [x^3 + 0.4x]_0^{0.2}$$

$$V = (0.2)^3 + 0.4 \times 0.2 = 0.088 \text{ volt}$$

$$C = \frac{Q}{V} = \frac{0.88}{0.088} = 10 \mu\text{F}$$

15. (a, c, d)

$$(a) E = \frac{1}{2} CV^2$$

As potential difference source between the plates is connected, P.D. remains constant. But capacitance C becomes KC , hence energy stored is increased by factor K .

(b) Electric field $\frac{V}{d}$ is not changed.

(c) Charge on each plate is increased by factor K , hence force between them increases by factor K^2 . For effect of the medium, they must completely lie in the medium.

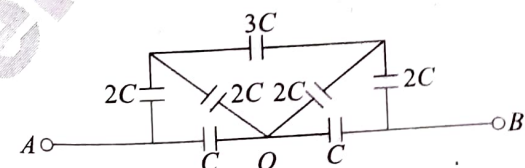
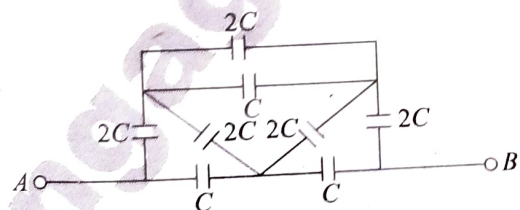
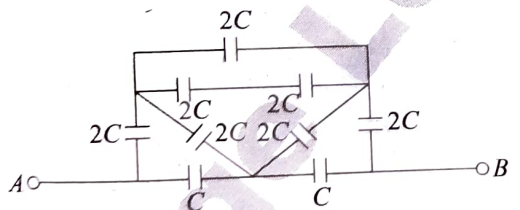
$$(d) Q = CV$$

Hence charge becomes KQ as C becomes KC and V remains unchanged.

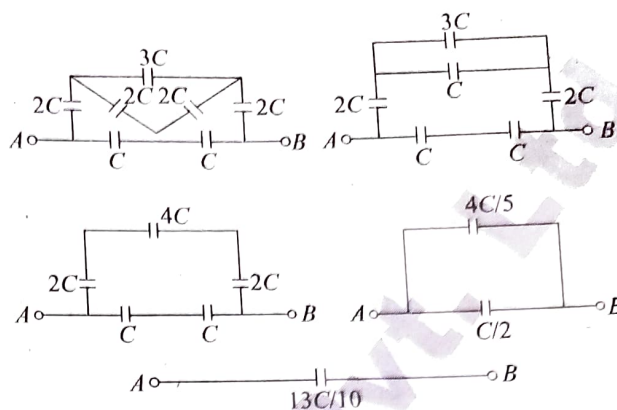
DPP 4.2

Subjective Type

1. The circuit as shown in the figure is symmetric about line AB , so the points P and S and Q and R are at the same potential. So the P and S and Q and R can be joined. That is, the circuit can be folded about line AB .



Due to reverse symmetry (i.e., the circuit appears to be the same when seen from point A or point B), the junction ' O ' can be broken as shown in the figure.



Hence the equivalent capacitance between the points A and B

$$\text{is } \frac{13}{10}C = \frac{13}{10} \times 10 \mu\text{F} = 13 \mu\text{F}.$$

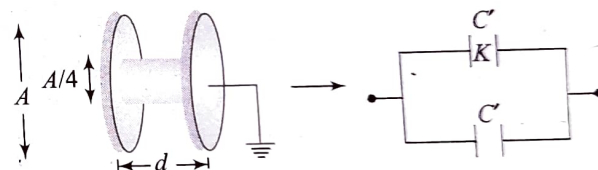
Single Correct Answer Type

2. (d) Area of the given metallic plate $A = \pi r^2$

$$\text{Area of the dielectric plate } A' = \pi \left(\frac{r}{2}\right)^2 = \frac{A}{4}$$

$$\text{Uncovered area of the metallic plates } A'' = A - A'$$

$$= A - \frac{A}{4} = \frac{3A}{4}$$

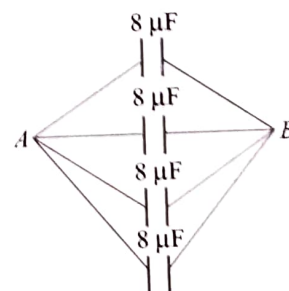


The given situation is equivalent to a parallel combination of two capacitors. One capacitor (C') is filled with a dielectric medium ($K=6$) having area $\frac{A}{4}$, while the other capacitor (C'') is air filled having area $\frac{3A}{4}$.

$$\text{Hence } C_{eq} = C' + C'' = \frac{K\epsilon_0(A/4)}{d} + \frac{\epsilon_0(3A/4)}{d}$$

$$= \frac{\epsilon_0 A}{d} \left(\frac{K}{4} + \frac{3}{4} \right) = \frac{\epsilon_0 A}{d} \left(\frac{6}{4} + \frac{3}{4} \right) = \frac{9}{4} C \quad \left(\because C = \frac{\epsilon_0 A}{d} \right)$$

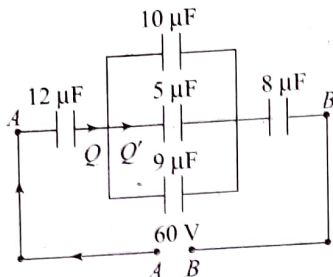
3. (a) Given circuit can be drawn as



$$\text{Equivalent capacitance} = 4 \times 8 = 32 \mu\text{F}$$

S.30 Electrostatics and Current Electricity

4. (d) The given circuit can be redrawn as follows



Equivalent capacitance of the circuit $C_{AB} = 4 \mu\text{F}$

Charge given by the battery

$$Q = C_{eq} V = 4 \times 60 = 240 \mu\text{C}$$

$$\text{Charge in } 5 \mu\text{F capacitor } Q' = \frac{5}{(10 + 5 + 9)} \times 240 = 50 \mu\text{C}$$

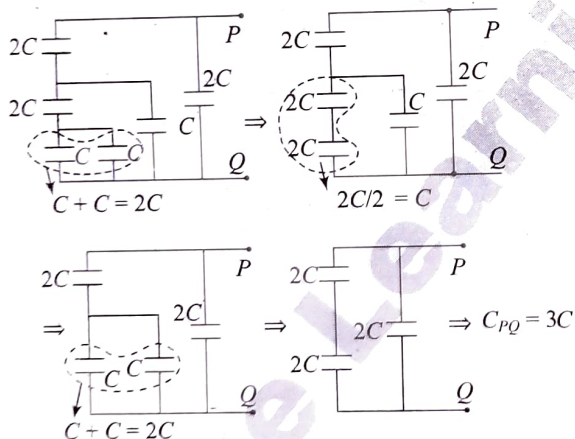
5. (d) Total capacitance $\frac{1}{C} = \frac{1}{20} + \frac{1}{8} + \frac{1}{12} \Rightarrow C = \frac{120}{31} \mu\text{F}$

$$\text{Total charge } Q = CV = \frac{120}{31} \times 300 = 1161 \mu\text{C}$$

$$\text{Charge through } 4 \mu\text{F condenser} = \frac{1161}{2} = 580 \mu\text{C}$$

$$\text{and potential difference across it} = \frac{580}{4} = 145 \text{ V}$$

6. (a)



7. (b) There are two capacitors parallel to each other.

$$\therefore \text{Total capacitance} = \frac{2\epsilon_0 A}{d}$$

$$\therefore \text{Energy stored} = \frac{1}{2} \left(\frac{2\epsilon_0 A}{d} \right) V^2$$

$$= \frac{8.86 \times 10^{-12} \times 50 \times 10^{-4} \times 12^2}{3 \times 10^{-3}} = 2.1 \times 10^{-9} \text{ J}$$

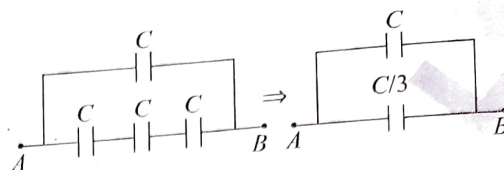
8. (b) In series combination of capacitors, voltage distributes on them in the reverse ratio of their capacitance, i.e., $\frac{V_A}{V_B} = \frac{3}{2}$ (i)

(ii)

$$\text{Also } V_A + V_B = 10$$

On solving (i) and (ii) $V_A = 6 \text{ V}$, $V_B = 4 \text{ V}$

9. (d)



$$\Rightarrow C_{eq} = \frac{C}{3} + C = \frac{4C}{3}$$

10. (c) According to the graph we can say that potential difference across the capacitor C_1 is more than that across C_2 . Since charge Q is the same, i.e., $Q = C_1 V_1 = C_2 V_2$

$$\Rightarrow \frac{C_1}{C_2} = \frac{V_2}{V_1} \Rightarrow C_1 < C_2 \quad (V_1 > V_2)$$

11. (c) Given circuit can be redrawn as follows capacitor, $9 \mu\text{F}$, $9 \mu\text{F}$ and $7 \mu\text{F}$ are short circuited. Hence, they are deleted.

$$V_1 + V_2 = 40 \text{ V}$$

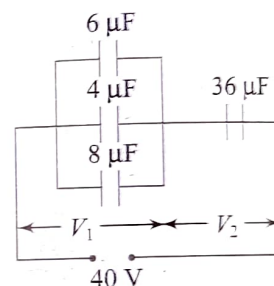
$$\text{and } \frac{V_1}{V_2} = \frac{36}{18} = 2$$

$$\text{Hence } V_1 = \frac{80}{3} \text{ V}$$

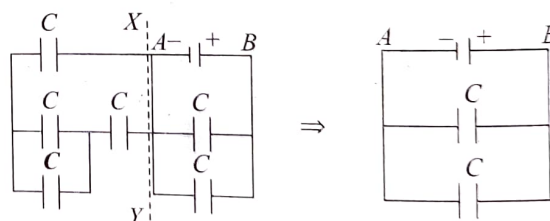
$$\text{and } V_2 = \frac{40}{3} \text{ V}$$

Charge on $8 \mu\text{F}$ capacitor

$$= 8 \times \frac{80}{3} = 213.3 \mu\text{F} \approx 214 \mu\text{F}$$



12. (d) All capacitors lying in the left side of line XY are short circuited so circuit can be reduced as follows



$$C_{AB} = 2C$$

13. (c) $Q_1 = Q_2 + Q_3$ because in series combination charge is the same on both the condenser and $V = V_1 + V_2$ because in parallel combination $V_2 = V_3$

$$\text{Hence } V = V_1 + V_2$$

14. (a) $\frac{1}{C_{eff}} = \frac{1}{C_1} + \frac{1}{C_2} = \frac{d_1}{\epsilon_0 A} + \frac{d_2}{\epsilon_0 A} = \frac{(d_1 + d_2)}{\epsilon_0 A}$

Since $(d_1 + d_2)$ does not change, C_{eff} remains unchanged.

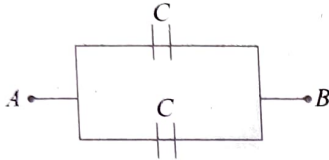
DPP 4.3

Single Correct Answer Type

- (a) The given circuit is equivalent to a parallel combination of two identical capacitors

Hence equivalent capacitance between A and B is

$$C = \frac{\epsilon_0 A}{d} + \frac{\epsilon_0 A}{d} = \frac{2\epsilon_0 A}{d}$$



2. (c) Initial energy $U_i = \frac{1}{2} C_1 V_1^2 + \frac{1}{2} C_2 V_2^2$,

Final energy $U_f = \frac{1}{2} (C_1 + C_2) V^2$ (where $V = \frac{C_1 V_1 + C_2 V_2}{C_1 + C_2}$)

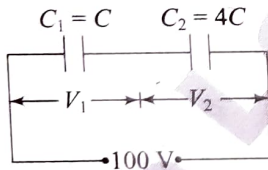
Hence energy loss $\Delta U = U_i - U_f = \frac{C_1 C_2}{2(C_1 + C_2)} (V_1 - V_2)^2$

3. (b) $C_{eq} = \frac{C \times 4C}{C + 4C} = \frac{4C}{5}$

$Q = C_{eq} \cdot V = \frac{4C}{5} \times 100 = 80C$

Hence $V_1 = \frac{Q}{C_1} = \frac{80C}{C_1} = 80V$

and $V_2 = \frac{80C}{4C} = 20V$



4. (d) $C_1 + C_2 + C_3 = 12$

$C_1 C_2 C_3 = 48$

$C_1 + C_2 = 6$

From equations (i) and (iii)

$C_3 = 6$

From equations (ii) and (iv) $C_1 C_2 = 8$

Also $(C_1 - C_2)^2 = (C_1 + C_2)^2 - 4C_1 C_2$

$(C_1 - C_2)^2 = (6)^2 - 4 \times 8 = 4$

$\Rightarrow C_1 - C_2 = 2$

On solving (iii) and (v) $C_1 = 4, C_2 = 2$

5. (b) $C_1 = \frac{K_1 \epsilon_0 \frac{A}{2}}{\left(\frac{d}{2}\right)} = \frac{K_1 \epsilon_0 A}{d}$

$$C_2 = \frac{K_2 \epsilon_0 \frac{A}{2}}{\left(\frac{d}{2}\right)} = \frac{K_2 \epsilon_0 A}{d} \text{ and } C_3 = \frac{K_3 \epsilon_0 A}{\left(\frac{d}{2}\right)} = \frac{2K_3 \epsilon_0 A}{d}$$

$$\frac{1}{C_{eq}} = \frac{1}{C_1 + C_2} + \frac{1}{C_3} = \frac{1}{\frac{\epsilon_0 A}{d} (K_1 + K_2)} + \frac{1}{\frac{\epsilon_0 A}{d} \times 2K_3}$$

$$\frac{1}{C_{eq}} = \frac{d}{\epsilon_0 A} \left[\frac{1}{K_1 + K_2} + \frac{1}{2K_3} \right]$$

$$C_{eq} = \left[\frac{1}{K_1 + K_2} + \frac{1}{2K_3} \right]^{-1} \frac{\epsilon_0 A}{d}$$

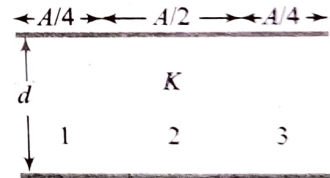
$$\therefore K_{eq} = \left[\frac{1}{K_1 + K_2} + \frac{1}{2K_3} \right]^{-1}$$

6. (d) $C_1 = \frac{K_1 \epsilon_0 \frac{A}{2}}{\left(\frac{d}{2}\right)} = \frac{K_1 \epsilon_0 A}{d}$

$$C_2 = \frac{K_2 \epsilon_0 \left(\frac{A}{2}\right)}{\left(\frac{d}{2}\right)} = \frac{K_2 \epsilon_0 A}{d} \text{ and } C_3 = \frac{K_3 \epsilon_0 A}{2d}$$

Now, $C_{eq} = C_3 + \frac{C_1 C_2}{C_1 + C_2} = \left(\frac{K_3}{2} + \frac{K_1 K_2}{K_1 + K_2} \right) \cdot \frac{\epsilon_0 A}{d}$

7. (a) $C_1 = \frac{\epsilon_0 \left(\frac{A}{4}\right)}{d}, C_2 = \frac{K \epsilon_0 \left(\frac{A}{2}\right)}{d}, C_3 = \frac{\epsilon_0 \left(\frac{A}{4}\right)}{d}$

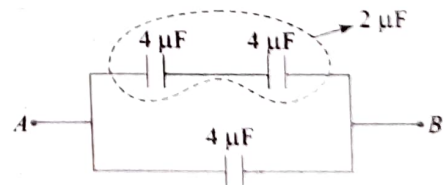


$$C_{eq} = C_1 + C_2 + C_3 = \left(\frac{K+1}{2} \right) \frac{\epsilon_0 A}{d} = \left(\frac{4+1}{2} \right) \times 10 = 25 \mu F$$

- (i)
(ii)
(iii)

8. (b) The given circuit can be drawn as follows

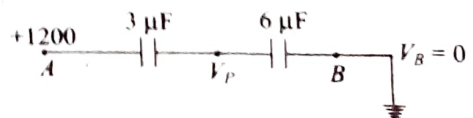
- (iv)



- (v)

$$\Rightarrow C_{AB} = 2 + 4 = 6 \mu F$$

9. (c) Given circuit can be reduced as follows

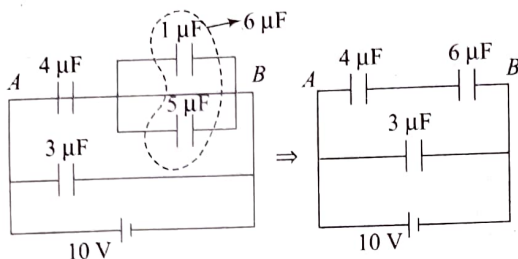


S.32 Electrostatics and Current Electricity

In series combination, charge on each capacitor remains the same. So using $Q = CV$

$$\begin{aligned} \Rightarrow C_1 V_1 &= C_2 V_2 \Rightarrow 3(1200 - V_p) = 6(V_p - V_B) \\ \Rightarrow 1200 - V_p &= 2V_p \quad (\because V_B = 0) \\ \Rightarrow 3V_p &= 1200 \Rightarrow V_p = 400 \text{ V} \end{aligned}$$

10. (b) Equivalent capacity between A and B $= \frac{6 \times 4}{10} = 2.4 \mu\text{F}$



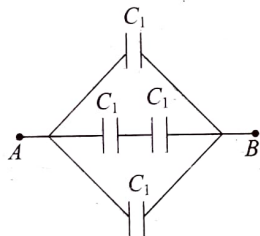
Hence charge across is $4 \mu\text{F}$. Since in series combination charge remains constant or $6 \mu\text{F} = 2.4 \times 10 = 24 \mu\text{C}$

11. (d) The capacitance across A and B

$$= \frac{C_1}{2} + C_1 + C_1 = \frac{5}{2} C_1$$

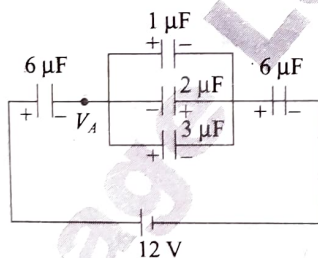
As $Q = CV$,

$$1.5 \mu\text{C} = \frac{5}{2} C_1 \times 6$$



$$\Rightarrow C_1 = \frac{1.5}{15} \times 10^{-6} = 0.1 \times 10^{-6} \text{ F} = 0.1 \mu\text{F}$$

12. (b) $C_{eq} = 2 \mu\text{F}$, $Q = 24 \mu\text{C}$



$$V_A + \frac{24}{6} = 12 \Rightarrow V_A = 8 \text{ V}$$

$$q_1 + q_2 + q_3 = 24$$

$$(1 \times 8) + q_2 + (3 \times 8) = 24$$

$$q_2 = -8 \mu\text{C}$$

13. (a) When K_1 is closed, plates A and B from a parallel plate capacitor and plate C do not play any role (K_2 is open). Hence, charge Q will appear on the left side of plate B and $-Q$ on the right side of plate A, which will flow through K_1 to plate D. The current on plate D is not induced current, hence there is no role of dielectric constant K .

14. (b) $V = Q/C = \text{constant}$ as capacitors are in parallel.

$$\frac{Q_1}{Q_2} = \frac{C_1}{C_2} = \frac{d}{t} \left(C_1 = \frac{\epsilon_0 A}{t} \text{ and } C_2 = \frac{\epsilon_0 A}{d} \right)$$

$$\frac{Q_2}{Q_1 + Q_2} = \frac{t}{d + t}$$

$$Q_2 = \frac{t}{(d + t)} \cdot Q$$

$$\text{and } Q_1 = \frac{d}{(d + t)} \cdot Q$$

DPP 4.4

Subjective Type

1. In the circuit, when initially K_1 is closed and K_2 is open, the capacitors C_1 and C_2 acquire potential differences V_1 and V_2 respectively. So, we have

$$V_1 + V_2 = E \text{ and } V_1 + V_2 = 9 \text{ V}$$

$$\text{Also, in series combination, } V \propto \frac{1}{C}$$

$$V_1 : V_2 = 1/6 : 1/3$$

On solving

$$\Rightarrow V_1 = 3 \text{ V and } V_2 = 6 \text{ V}$$

$$Q_1 = C_1 V_1 = 6 \text{ C} \times 3 = 18 \mu\text{C}$$

$$Q_2 = 9 \mu\text{C and } Q_3 = 0$$

Then K_1 was opened and K_2 was closed, the parallel combination of C_2 and C_3 is in series with C_1 .

$$C_2 V + C_3 V = Q_2$$

and considering common potential of parallel combination as V , then we have

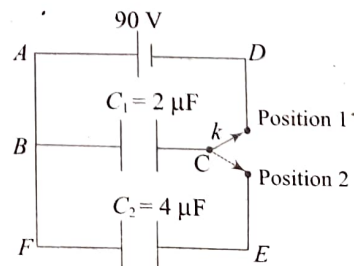
$$C_2 V + C_3 V = Q_2$$

$$\Rightarrow V = \frac{Q_2}{C_2 + C_3} = \frac{3}{2} \text{ V}$$

$$\text{On solving, } Q'_2 = \frac{9}{2} \mu\text{C}$$

$$\text{and } Q_3 = \frac{9}{2} \mu\text{C}$$

2. Initially when key k is in position 1, charge on C_1 is $Q_1 = 180 \mu\text{C}$



As the key is pushed to position 2, C_1 and C_2 are in parallel

$$\therefore \text{Charge on } C_2 \text{ is } q_2 = C_2 \left(\frac{\text{net charge on } C_1 \text{ and } C_2}{C_1 + C_2} \right)$$

$$= 4 \times \frac{180}{6} = 120 \mu\text{C}$$

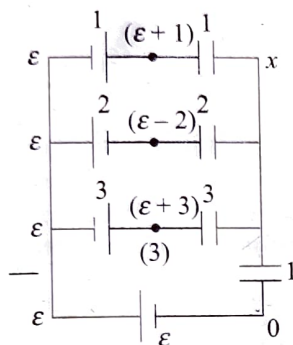
Again when key k is pushed to position 1, charge on C_1 is $Q_1 = 180 \mu\text{C}$

As the key is again pushed to position 2,

$$\therefore \text{Charge on } C_2 \text{ is } q_2 = C_2 \left(\frac{\text{net charge on } C_1 \text{ and } C_2}{C_1 + C_2} \right)$$

$$= 4 \times \frac{180 + 120}{6} = 200 \mu\text{C}$$

3. So,



$$(x - \varepsilon - 1) + 2(x - \varepsilon + 2) + 3(x - \varepsilon - 3) + (x - 0) = 0$$

$$\Rightarrow 7x - 6\varepsilon = 6 \quad (1) \text{ and } 2(x - \varepsilon + 2) = 4 \quad (\text{given})$$

$$\text{So, } 2x - 2\varepsilon = 0 \quad (2) \text{ giving } x = \varepsilon$$

$$\text{Hence } \varepsilon = x = 6 \text{ V}$$

$$\text{Also, we can have } 2(\varepsilon - 2 - x) = 4$$

$$\text{So, } \varepsilon - x = 4 \quad (3)$$

$$\text{From (1) and (3) we get } x = 30$$

$$\text{So } \varepsilon = 6 \text{ V or } \varepsilon = 34 \text{ V}$$

Single Correct Answer Type

4. (c) Let q_1 and q_2 be the charges on two condensers

$$\therefore V = \frac{q_1}{6} = \frac{q_2}{14} \Rightarrow \frac{q_1}{6} = \frac{q_2}{14} = \frac{3}{7}$$

$$\text{Also } q_1 + q_2 = 600 \Rightarrow q_1 + \frac{14}{6}q_1 = 600$$

$$\Rightarrow q_1 = \frac{600}{20} \times 6$$

$$\therefore V = \frac{q_1}{6} = \frac{600}{20} = 30 \text{ volt}$$

5. (a) The total energy before connection

$$= \frac{1}{2} \times 4 \times 10^{-6} \times (50)^2 + \frac{1}{2} \times 2 \times 10^{-6} \times (100)^2$$

$$= 1.5 \times 10^{-2} \text{ J}$$

When connected in parallel

$$4 \times 50 + 2 \times 100 = 6 \times V \Rightarrow V = \frac{200}{3}$$

Total energy after connection

$$= \frac{1}{2} \times 6 \times 10^{-6} \times \left(\frac{200}{3} \right)^2 = 1.33 \times 10^{-2} \text{ J}$$

$$6. (a) \text{ Loss of energy during sharing} = \frac{C_1 C_2 (V_1 - V_2)^2}{2(C_1 + C_2)}$$

In the equation, put $V_2 = 0$, $V_1 = V_0$

$$\therefore \text{Loss of energy} = \frac{C_1 C_2 V_0^2}{2(C_1 + C_2)}$$

$$= \frac{C_2 U_0}{C_1 + C_2} \left[\because U_0 = \frac{1}{2} C_1 V_0^2 \right]$$

$$7. (c) \text{ Common potential } V = \frac{6 \times 20 + 3 \times 0}{(6 + 3)} = \frac{120}{9} \text{ V}$$

So, charge on $3 \mu\text{F}$ capacitor

$$Q_2 = 3 \times 10^{-6} \times \frac{120}{9} = 40 \mu\text{C}$$

8. (b) Initially potential difference across each capacitor

$$V_1 = \frac{20}{(10 + 20)} \times 200 = \frac{400}{3} \text{ V}$$

$$\text{and } V_2 = \frac{10}{(10 + 20)} \times 200 = \frac{200}{3} \text{ V}$$

$$\text{Finally common potential } V = \frac{C_1 V_1 + C_2 V_2}{C_1 + C_2}$$

$$V = \frac{10 \times \frac{400}{3} + 20 \times \frac{200}{3}}{(10 + 20)} = \frac{800}{9} \text{ V}$$

9. (c) Charge on $C_1 = \text{charge on } C_2$

$$\Rightarrow C_1(V_A - V_D) = C_2(V_D - V_B)$$

$$\Rightarrow C_1(V_1 - V_D) = C_2(V_D - V_2) \Rightarrow V_D = \frac{C_1 V_1 + C_2 V_2}{C_1 + C_2}$$

10. (c) Initial energy of the system

$$U_i = \frac{1}{2} C V_1^2 + \frac{1}{2} C V_2^2$$

When the capacitors are joined, common potential

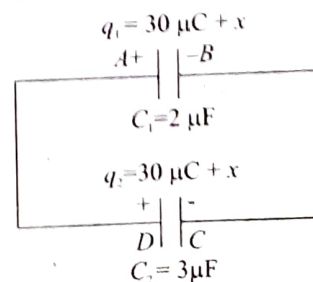
$$V = \frac{C V_1 + C V_2}{2C} = \frac{V_1 + V_2}{2}$$

Final energy of the system

$$U_f = \frac{1}{2} (2C) V^2 = \frac{1}{2} 2C \left(\frac{V_1 + V_2}{2} \right)^2 = \frac{1}{4} C (V_1 + V_2)^2$$

$$\text{Decrease in energy} = U_i - U_f = \frac{1}{4} C (V_1 - V_2)^2$$

11. (c) Let the charge flown from AB to CD be x .



$$\frac{30 + x}{2} + \frac{30 + x}{3} = 0$$

S.34 Electrostatics and Current Electricity

$$x = -30 \mu\text{C}$$

$\therefore$ Charge flown from A to D is $+30 \mu\text{C}$.

12. (a, b, c)

When S_1 is closed, only C is charged.

Charge through the battery $Q = CV = 120 \mu\text{C}$

As S_1 is opened and S_2 is closed, the charge is redistributed between C_1 and C_2 . Let these be Q_1 and Q_2 .

$$Q_1 + Q_2 = 120 \mu\text{C} \quad (1)$$

Using KVL in closed loop

$$\frac{Q_1}{C_1} - \frac{Q_2}{C_2} = 0 \Rightarrow \frac{Q_1}{C_1} = \frac{Q_2}{C_2}$$

Solving $Q_1 = 80 \mu\text{C}$

$$Q_1 = 40 \mu\text{C}$$

$$\Delta H = \left[\frac{Q^2}{2C_1} \right] - \left[\frac{Q_1^2}{2C_1} + \frac{Q_2^2}{2C_2} \right] = 400 \times 10^{-6} \text{ J}$$

Multiple Correct Answers Type

13. (a, c, d)

When key K_1 is closed and key K_2 is open, the capacitor C_1 is charged by the cell and when K is opened and K_2 is closed, the charge stored by capacitor C_1 gets redistributed between C_1 and C_2 .

The charge stored by capacitor C_1 gets redistributed between C_1 and C_2 till their potentials become the same, i.e., $V_2 = V_1$. By

law of conservation of charge, the charge stored in capacitor C_1 when key K_1 is closed and key K_2 is open is equal to the sum of charges on capacitors C_1 and C_2 when K_1 is opened and K_2 is closed, i.e.,

$$Q'_1 + Q'_2 = C_1 E$$

14. (a, c)

Net charge on both the capacitors is $C_1 V - C_2 V$. The effective capacitance of system is $C_1 + C_2$ because both are in parallel.

Therefore PD across the system is

$$\frac{Q_{\text{eff}}}{C_1 + C_2} = \frac{(C_1 - C_2)V}{C_1 + C_2}$$

$$\text{Initial energy} = \frac{1}{2}(C_1 + C_2)V^2$$

$$\text{Final energy} = \frac{1}{2}(C_1 + C_2) \left(\frac{(C_1 - C_2)V}{C_1 + C_2} \right)^2$$

Therefore the ratio of final to initial energy is $\left(\frac{(C_1 - C_2)}{(C_1 + C_2)} \right)^2$

15. (a, d)

Because $C_1 = C_2$ and C_1, C_2 are in parallel.

$$\therefore Q_0 = Q_1 = Q_2 \quad \therefore Q_0 = \frac{1}{2}(Q_1 + Q_2)$$

$$\text{Also } U_0 = U_1 = U_2 \quad \therefore U_0 \neq \frac{1}{2}(U_1 + U_2)$$

$$Q_0 = \frac{1}{2} \left(\frac{U_1}{Q_1} + \frac{U_2}{Q_2} \right) \text{ is dimensionally incorrect}$$

CHAPTER 5

DPP 5.1

Subjective Type

1. When an electron approaches a junction, in addition to the uniform electric field E facing it normally. It keeps the drift velocity fixed as drift velocity depends on E by the relation drift velocity

$$v_d = \frac{eE\tau}{m}$$

This results into accumulation of charges on the surface of wires at the junction. These produce additional electric field. These fields change the direction of momentum.

Thus, the motion of a charge across junction is not momentum conserving.

2. The higher drift velocities of electrons make collisions more frequent which in turn decreases the time interval between two successive collisions. Relaxation time is inversely proportional to the velocities of electrons and ions. The applied electric field produces the insignificant changes in velocities of electrons at the order of 1 mm/s, whereas the change in temperature (T) affects velocities at the order of 10^2 m/s.

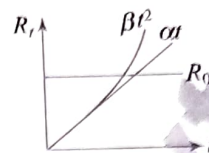
This decreases the relaxation time considerably in metals and consequently resistivity of metal or conductor increases as shown below:

$$\rho = \frac{1}{\sigma} = \frac{m}{ne^2\tau}$$

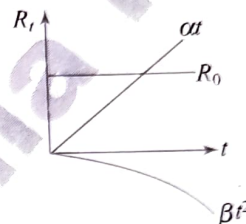
Single Correct Answer Type

3. (c) For figure (i) $i_1 = 7$ A
For figure (ii) $i_2 = 4 + 3 = 7$ A
For figure (iii) $i_3 = 5 + 2 = 7$ A
For figure (iv) $i_4 = 6 - 1 = 5$ A
4. (d) From the curve, it is clear that slopes at points A, B, C and D have the following order $A > B > C > D$.
And also resistance at any point equals to slope of the $V-i$ curve.
So the order of resistance at three points will be
 $R_A > R_B > R_C > R_D$
5. (d) Slope of $V-i$ curve $= R \left(= \frac{\rho l}{A} \right)$. But in given curve axes of i and V are interchanged. So the slope of given curve $= \frac{1}{R} \left(= \frac{A}{\rho l} \right)$, i.e., with the increase in the length of the wire. Slope of the curve will decrease.
6. (b) Since the value of R increases continuously, both α and β must be positive.

Actually the components of the given equation are as follows



If α is positive and β is negative, the component will be shown in the following graph.



In this case, the value of R will not increase continuously. Hence the correct option is (c).

7. (c) As we know, for conductors resistance $\propto$ temperature

$$\text{From figure } R_1 \propto T_1 \Rightarrow \tan \theta \propto T_1 \Rightarrow \tan \theta = kT_1 \quad (i)$$

$$\text{and } R_2 \propto T_2 \Rightarrow \tan (90^\circ - \theta) \propto T_2 \Rightarrow \cot \theta = kT_2 \quad (ii)$$

From equations (i) and (ii)

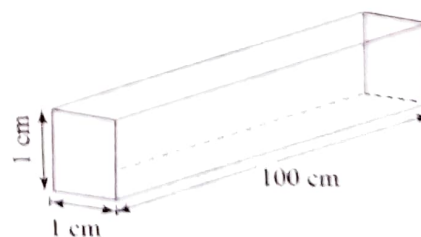
$$k(T_2 - T_1) = (\cot \theta - \tan \theta)$$

$$(T_2 - T_1) = \left(\frac{\cos \theta}{\sin \theta} - \frac{\sin \theta}{\cos \theta} \right)$$

$$= \frac{(\cos^2 \theta - \sin^2 \theta)}{\sin \theta \cos \theta} = 2 \cot 2\theta$$

$$\Rightarrow (T_2 - T_1) \propto \cot 2\theta$$

8. (b) Let resistivity at a distance ' x ' from left end be $\rho = (\rho_0 + \alpha x)$. Then electric field intensity at a distance ' x ' from left end will be equal to $E = \frac{i\rho}{A} = \frac{i(\rho_0 + \alpha x)}{A}$ where i is the current flowing through the conductor. It means $E \propto \rho$ or E varies linearly with distance ' x '. But at $x = 0$, E has non-zero value. Hence (b) is correct.
9. (b) Length $l = 1 \text{ cm} = 10^{-2} \text{ m}$



$$\text{Area of cross-section } A = 1 \text{ cm} \times 100 \text{ cm} = 100 \text{ cm}^2 = 10^{-2} \text{ m}^2$$

$$\text{Resistance } R = 3 \times 10^{-7} \times \frac{10^{-2}}{10^{-2}} = 3 \times 10^{-7} \Omega$$

S.36 Electrostatics and Current Electricity

10. (d) In the above question for calculating equivalent resistance between the two opposite square faces.

$$l = 100 \text{ cm} = 1 \text{ m}, A = 1 \text{ cm}^2 = 10^{-4} \text{ m}^2,$$

$$\text{so resistance } R = 3 \times 10^{-7} \times \frac{1}{10^{-4}} = 3 \times 10^{-3} \Omega$$

11. (d) If E is electric field, then current density $j = \sigma E$

$$\text{Also we know that current density } j = \frac{i}{A}$$

Hence j is different for different area of cross-sections. When j is different, then E is also different. Thus E is not constant. The

drift velocity v_d is given by $v_d = \frac{j}{ne}$ = different for different j values. Hence only current i will be constant.

12. (c) Drift velocity $v_d = \frac{i}{neA} \Rightarrow v_d \propto \frac{1}{A}$ or $v_d \propto \frac{1}{d^2}$

$$\frac{v_P}{v_Q} = \left(\frac{d_Q}{d_P} \right)^2 = \left(\frac{d/2}{d} \right)^2 = \frac{1}{4} \Rightarrow v_P = \frac{1}{4} v_Q$$

13. (c) $\frac{R_1}{R_2} = \left(\frac{l_1}{l_2} \right)^2$, If $l_1 = 100$, then $l_2 = 110$

$$\Rightarrow \frac{R_1}{R_2} = \left(\frac{100}{110} \right)^2 \Rightarrow R_2 = 1.21 R_1$$

$$\% \text{ change } \frac{R_2 - R_1}{R_1} \times 100 = 21\%$$

14. (a) The relationship between current and drift speed is given by

$$I = neAv_d$$

Here, I the current and v_d is the drift velocity.

So, $I \propto v_d$

Thus, only drift velocity determines the current in a conductor.

Multiple Correct Answers Type

15. (a, b)

The resistivity of a metallic conductor is given by,

$$\rho = \frac{m}{ne^2 \tau}$$

where n is the number of charge carriers per unit volume which can change with temperature T and τ is time interval between two successive collisions which decreases with the increase of temperature.

DPP 5.2

Subjective Type

1. The resistance of the cylindrical solid is $R = \int_0^L \frac{\rho dx}{\pi a^2} = \frac{\rho L}{\pi a^2}$

The current through cross-section of the cylindrical solid is

$$\therefore I = \frac{V}{R} = \frac{2\pi a^2 V}{b \cdot L^2}$$

The electric field at a distance x from the left end of the cylindrical rod is

$$E = \rho J = \frac{\rho I}{\pi a^2} = \frac{(bx) 2\pi V a^2}{\pi a^2 b L^2}$$

2. Resistance of the filament when bulb is on = $\frac{V}{I} = 9 \Omega$

Therefore using $R_t = R_0[1 + \alpha(\Delta T)]$

$$\Delta T = 2000^\circ \text{C}$$

$$T = 2000^\circ \text{C} + 20^\circ \text{C} = 2020^\circ \text{C}$$

Single Correct Answer Type

3. (c) $R_1 = R_1(1 + \alpha_1 t)$ and $R_2 = R_2(1 + \alpha_2 t)$

$$\text{Also } R_{eq} = R_1 + R_2 \Rightarrow R_{eq} = R_1 + R_2 + (R_1 \alpha_1 + R_2 \alpha_2)t$$

$$\Rightarrow R_{eq} = (R_1 + R_2) \left\{ 1 + \left(\frac{R_1 \alpha_1 + R_2 \alpha_2}{R_1 + R_2} \right) t \right\}$$

$$\text{So } \alpha_{eff} = \frac{R_1 \alpha_1 + R_2 \alpha_2}{R_1 + R_2}$$

4. (d) $R_1 + R_2 = R_1(1 + \alpha t) + R_2(1 - \beta t)$

$$\Rightarrow R_1 + R_2 = R_1 + R_2 + R_1 \alpha t - R_2 \beta t \Rightarrow \frac{R_1}{R_2} = \frac{\beta}{\alpha}$$

5. (d) Current density of drifting electrons $j = nev$

$$n = 5 \times 10^{27} \text{ cm}^{-3} = 5 \times 10^{27} \times 10^6 \text{ m}^{-3}$$

$$v = 0.4 \text{ ms}^{-1}, e = 1.6 \times 10^{-19} \text{ C} \Rightarrow j = 3.2 \times 10^{-6} \text{ Am}^{-2}$$

$$\text{Current density of ions} = (4 - 3.2) \times 10^{-6} = 0.8 \times 10^{-6} \frac{\text{A}}{\text{m}^2}$$

This gives v for ions = 0.1 ms^{-1}

6. (b) $dQ = Idt \Rightarrow Q = \int_{t=2}^{t=3} Idt = \left[2 \int_2^3 t dt + 3 \int_2^3 t^2 dt \right]$

$$= [t^2]_2^3 + [t^3]_2^3 = (9 - 4) + (27 - 8) = 5 + 19 = 24 \text{ C}$$

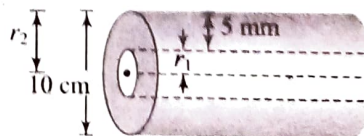
7. (a) $\frac{R_1}{R_2} = \frac{(1 + \alpha t_1)}{(1 + \alpha t_2)} \Rightarrow \frac{10}{R_2} = \frac{(1 + 5 \times 10^{-3} \times 20)}{(1 + 5 \times 10^{-3} \times 120)} \Rightarrow R_2 = 15 \Omega$

$$\text{Also } \frac{i_1}{i_2} = \frac{R_2}{R_1} \Rightarrow \frac{30}{i_2} = \frac{15}{10} \Rightarrow i_2 = 20 \text{ mA}$$

8. (a) By using $R = \rho \cdot \frac{l}{A}$; here $A = \pi(r_2^2 - r_1^2)$

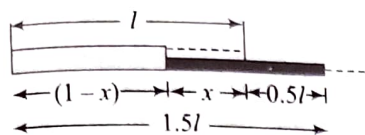
Outer radius $r_2 = 5 \text{ cm}$

Inner radius $r_1 = 5 - 0.5 = 4.5 \text{ cm}$



$$\text{So } R = 1.7 \times 10^{-8} \times \frac{5}{\pi \{ (5 \times 10^{-2})^2 - (4.5 \times 10^{-2})^2 \}} = 5.6 \times 10^{-5} \Omega$$

9. (a) Let l be the original length of the wire and x be its length stretched uniformly such that final length is $1.5l$



$$\text{Then } 4R = \rho \frac{(l-x)}{A} + \rho \frac{(0.5l+x)}{A'} \text{ where } A' = \frac{x}{(0.5l+x)} A$$

$$\therefore 4\rho \frac{l}{A} = \rho \frac{l-x}{A} + \rho \frac{(0.5l+x)^2}{xA}$$

$$\text{or } 4l = l - x + \frac{1}{4} \frac{l^2}{x} + \frac{x^2}{x} + \frac{lx}{x} \text{ or } \frac{x}{l} = \frac{1}{8}$$

10. (a) All the conductors have equal lengths. Area of cross-section of A is $\{(\sqrt{3}a)^2 - (\sqrt{2}a)^2\} = a^2$

Similarly area of cross-section of B = Area of cross-section of C = a^2

Hence according to formula, $R = \rho \frac{l}{A}$ resistances of all the

conductors are equal, i.e., $R_A = R_B = R_C$

11. (c) Let ρ be the resistivity of the material
Resistance for contact A-A

$$R_{AA} = \rho \frac{x}{2x \times 4x} = \frac{\rho}{8x}$$

Similar for contacts B-B and C-C are respectively

$$R_{BB} = \rho \cdot \frac{2x}{x \times 4x} = \frac{\rho}{2x} = \frac{4\rho}{8x}$$

$$\text{and } R_{CC} = \rho \frac{4x}{x \times 2x} = \frac{2\rho}{x} = \frac{16\rho}{8x}$$

It is clear that maximum resistance will be for contact C-C.

12. (d) Wire AB is uniform, so current through wire AB at every cross-section will be the same. Hence current density $J (= i/A)$ at every point of the wire will be the same.
13. (c) Two wires carry the same current

$$I = n_1 e A V_{d1} = n_2 e A V_{d2}$$

$$\text{So } n_1 V_{d1} = n_2 V_{d2}$$

$$\frac{V_{d1}}{V_{d2}} = \frac{n_1}{n_2} = 4$$

$$V_{d1} : V_{d2} = 4 : 1$$

14. (b) Current density $\Rightarrow J = \frac{I}{ds}$

$$\therefore (ds)_A < (ds)_B$$

$$\therefore J_A > J_B$$

$$15. (d) \quad j = \frac{i}{A} \text{ and } i = \frac{V}{R} \Rightarrow j = \frac{V}{RA}$$

$$\text{Using } R = \frac{1}{\sigma} \cdot \frac{l}{A} \quad j = \frac{V\sigma}{l} \text{ (or as } J = \sigma E)$$

$$\text{Using values } j = 20 \times 10^6 \text{ A/m}^2$$

DPP 5.3

Subjective Type

1. In series combination of resistors, current I is given by

$$I = \frac{E}{R + nR'}$$

Whereas in parallel combination current $10I$ is given by

$$\frac{E}{R + \frac{R}{n}} = 10I$$

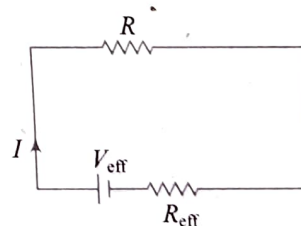
Now, according to problem,

$$\frac{1+n}{1+\frac{1}{n}} \Rightarrow 10 = \left(\frac{1+n}{n+1} \right) n \Rightarrow n = 10$$

2. Let the effective internal resistance of the battery is R_{eff} , the effective external resistance R and the effective voltage of the battery is V_{eff} .

Applying Ohm's law, then current through R is given by

$$I = \frac{V_{\text{eff}}}{R_{\text{eff}} + R}$$



If all the resistances and the effective voltage are increased n times, then we have

$$V_{\text{eff}}^{\text{new}} = nV_{\text{eff}}, R_{\text{eff}}^{\text{new}} = nR_{\text{eff}}$$

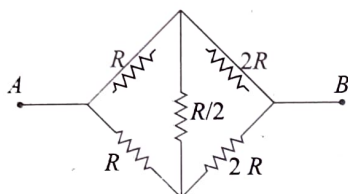
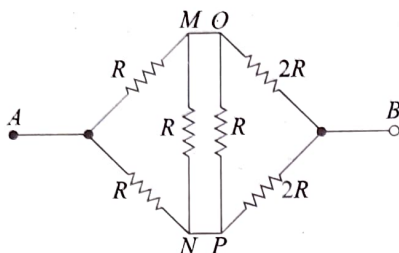
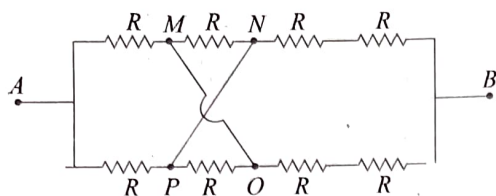
$$\text{and } R^{\text{new}} = nR$$

Then, the new current is given by

$$I' = \frac{nV_{\text{eff}}}{nR_{\text{eff}} + nR} = \frac{n(V_{\text{eff}})}{n(R_{\text{eff}} + R)} = \frac{(V_{\text{eff}})}{(R_{\text{eff}} + R)} = I$$

Thus, current remains the same.

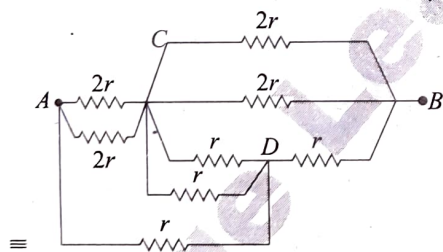
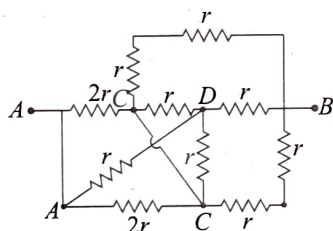
3.



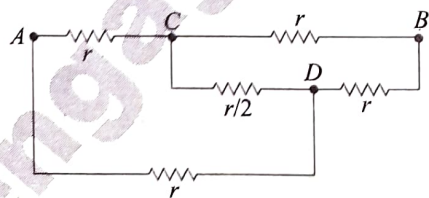
By Wheatstone balanced bridge, then equivalent resistance

$$= \frac{3R}{2} = 1.5R$$

4.



$\equiv R_{AB} \equiv r$ (By Wheatstone balanced bridge concept)



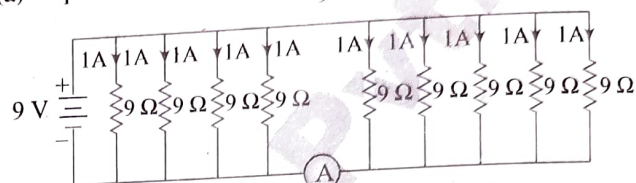
Single Correct Answer Type

5. (b) When we move in the direction of the current in a uniform conductor, the potential difference decreases linearly. When we

pass through the cell, from its negative to its positive terminal, the potential increases by an amount equal to its potential difference. This is less than its emf, as there is some potential drop across its internal resistance when the cell is driving current.

6. (a) $R_{\text{Parallel}} < R_{\text{Series}}$. From the graph it is clear that slope of the line A is lower than the slope of the line B. Also slope = resistance, so line A represents the graph for parallel combination.

7. (a) Equivalent resistance $R = \frac{9}{9} = 1 \Omega$

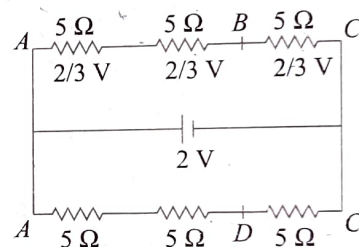


$$\text{Current } i = \frac{9}{1} = 9 \text{ A}$$

Current passes through the ammeter = 5 A

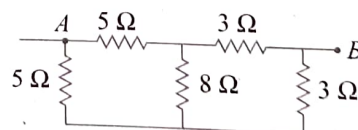
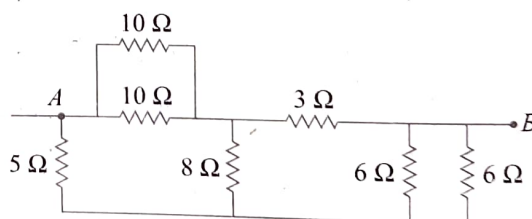
8. (d) Equivalent resistance of parallel resistors is always less than any of the member of the resistance system.

9. (c) The given circuit can be redrawn as follows:

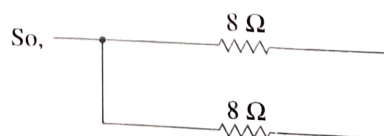


For identical resistances, potential difference distributes equally among all. Hence potential difference across each resistance is $\frac{2}{3}$ V, and potential difference between A and B is $\frac{4}{3}$ V.

10. (b) The given circuit can be simplified as follows



Now it is a balance Wheatstone bridge.



$$\Rightarrow R_{AB} = \frac{8 \times 8}{8 + 8} = \frac{64}{16} = 4 \Omega$$

2. By symmetry the current distribution is shown in Figure (a). No current will flow in HE and BG . So they can be removed. Hence the equivalent circuit is shown in Figure (b), which can be further simplified as shown in Figure (c).

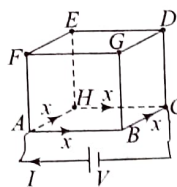


Figure (a)

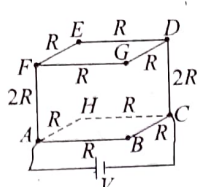


Figure (b)

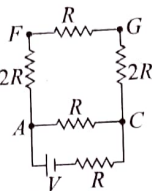


Figure (c)

The equivalent resistance of the circuit across AC is

$$\frac{1}{R_{eq}} = \frac{1}{R} + \frac{1}{5R}$$

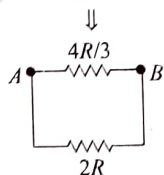
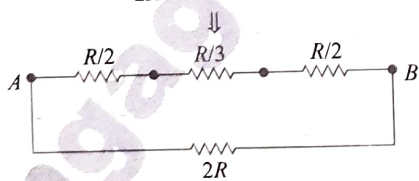
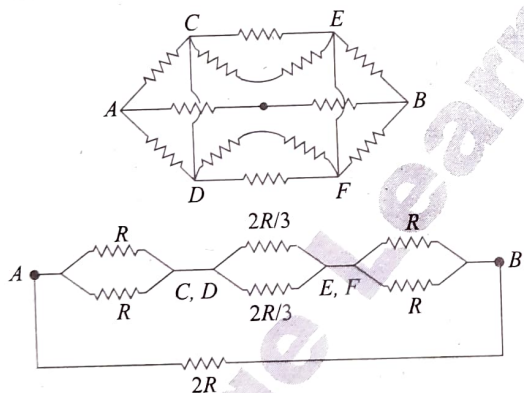
$$R_{eq} = \frac{5R}{6}$$

$$\text{Current through battery } I = \frac{V}{R + \frac{5R}{6}} = \frac{6V}{11R}$$

$$\therefore I_{AC} = I \cdot \frac{5R}{5R + R} = \frac{5V}{11R}; I_{AB} = \frac{I_{AC}}{2} = \frac{5V}{22R}$$

$$\therefore I_{AF} = I \cdot \frac{R}{5R + R} = \frac{V}{11R}; I_{ED} = \frac{I_{AF}}{2} = \frac{V}{22R}$$

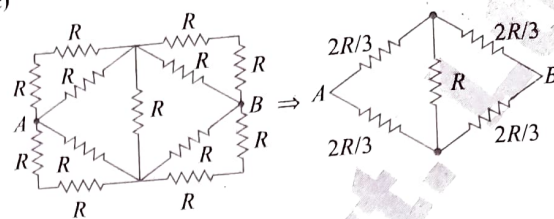
3. The current in CO , OE , DO and OF will be the same. So, these branches will not touch each other at O .



$$R_{eq} = \frac{4}{5}R$$

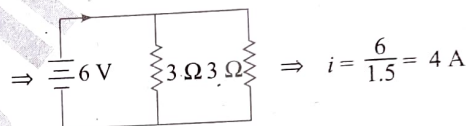
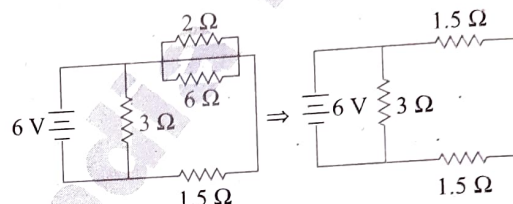
Single Correct Answer Type

4. (c)



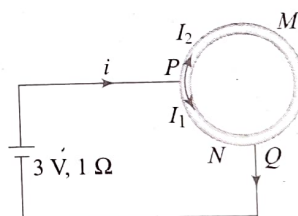
$$\text{Hence } R_{eq} = \frac{2R}{3}$$

5. (c) Given circuit can be redrawn as follows:



6. (a) In the following figure, Resistance of part PNQ ,

$$R_1 = \frac{10}{4} = 2.5 \Omega \text{ and}$$



Resistance of part PMQ ,

$$R_2 = \frac{3}{4} \times 10 = 7.5 \Omega$$

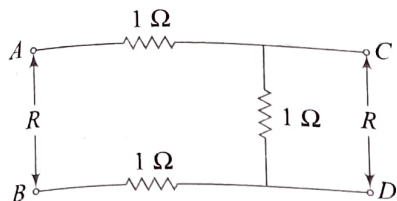
$$R_{eq} = \frac{R_1 R_2}{R_1 + R_2} = \frac{2.5 \times 7.5}{(2.5 + 7.5)} = \frac{15}{8} \Omega$$

$$\text{Main Current } i = \frac{3}{\frac{15}{8} + 1} = \frac{24}{23} \text{ A}$$

$$\text{So, } i_1 = i \times \left(\frac{R_2}{R_1 + R_2} \right) = \frac{24}{23} \times \left(\frac{7.5}{2.5 + 7.5} \right) = \frac{18}{23} \text{ A}$$

$$\text{and } i_2 = i - i_1 = \frac{24}{23} - \frac{18}{23} = \frac{6}{23} \text{ A}$$

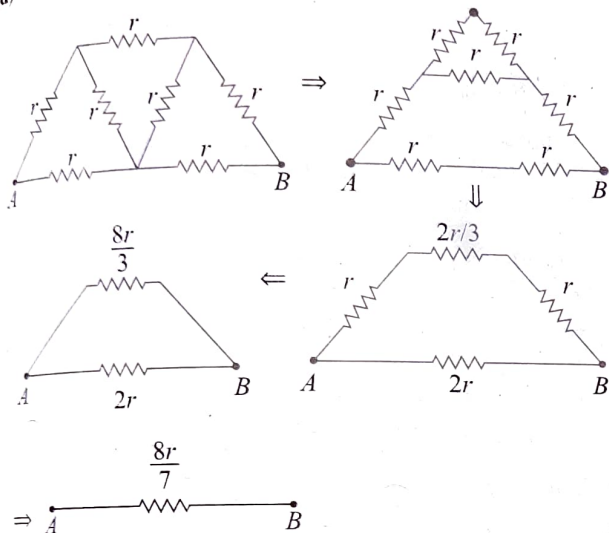
7. (c) Let equivalent resistance between A and B be R , then equivalent resistance between C and D will also be R .



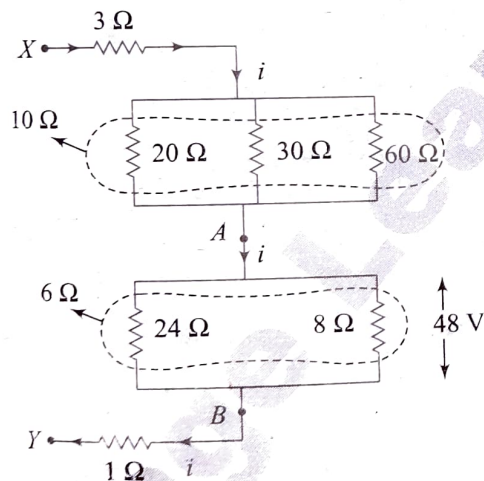
$$R' = \frac{R}{R+1} + 2 = R \text{ or } R^2 - 2R - 2 = 0$$

$$\therefore R = \frac{2 \pm \sqrt{4+8}}{2} = \sqrt{3} + 1$$

8. (d) The given circuit can be simplified as follows:



9. (a) The given circuit can be redrawn as follows:



$$\text{Resistance between A and B} = \frac{24 \times 8}{32} = 6 \Omega$$

$$\text{Current between A and B} = \text{Current between X and Y} \\ = i = \frac{48}{6} = 8 \text{ A}$$

$$\text{Resistance between X and Y} = (3 + 10 + 6 + 1) = 20 \Omega$$

$$\Rightarrow \text{Potential difference between X and Y} = 8 \times 20 = 160 \text{ V}$$

10. (a) If two resistances are R_1 and R_2 , then

$$S = R_1 + R_2 \text{ and } P = \frac{R_1 R_2}{(R_1 + R_2)}$$

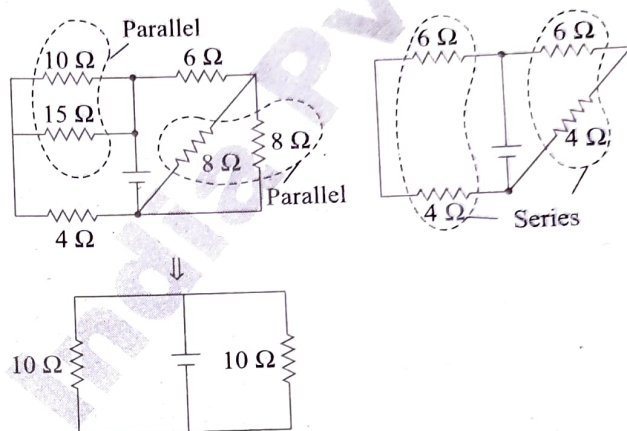
From given condition $S = nP$, i.e.,

$$(R_1 + R_2) = n \left(\frac{R_1 R_2}{R_1 + R_2} \right)$$

$$\Rightarrow (R_1 + R_2)^2 = n R_1 R_2 \Rightarrow (R_1 - R_2)^2 + 4 R_1 R_2 = n R_1 R_2$$

$$\text{So } n = 4 + \frac{(R_1 - R_2)^2}{R_1 R_2}. \text{ Hence minimum value of } n \text{ is } 4.$$

11. (c) Given circuit can be reduced to a simple circuit as shown in the following figures

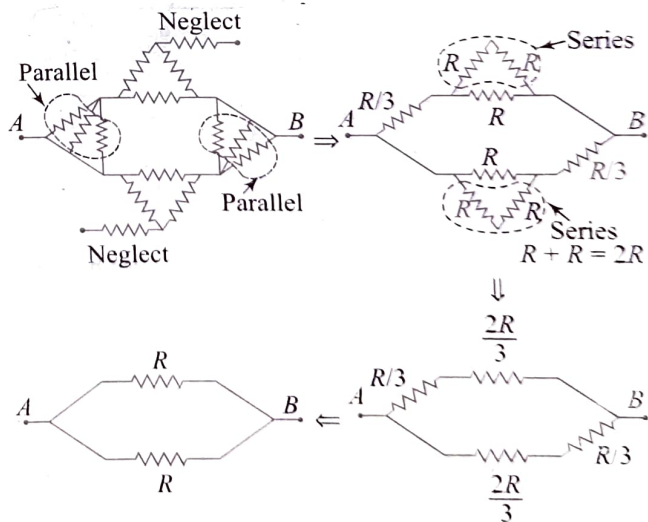


12. (b) Resistors are connected in series. So current through each resistor will be same

$$\Rightarrow i = \frac{12-8}{R_3} = \frac{8-4}{R_2} = \frac{4-0}{R_1} \Rightarrow \frac{4}{R_3} = \frac{4}{R_2} = \frac{4}{R_1}$$

$$\text{So, } R_1 : R_2 : R_3 :: 1 : 1 : 1.$$

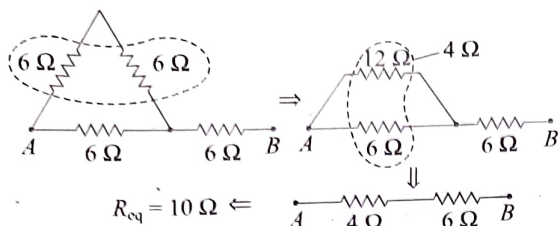
13. (c) Given circuit can be redrawn as follows:



$$\Rightarrow R_{eq} = \frac{R}{2}$$

$$\Rightarrow \frac{R_A}{R_B} = \frac{r_2^2 - r_1^2}{r_1^2} = \left(\frac{r_2}{r_1} \right)^2 - 1 = \left(\frac{d_2}{d_1} \right)^2 - 1 = \left(\frac{2}{1} \right)^2 - 1 = 3$$

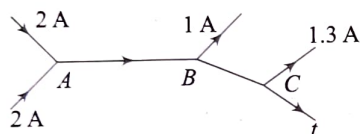
14. (b) Given resistance of each part will be



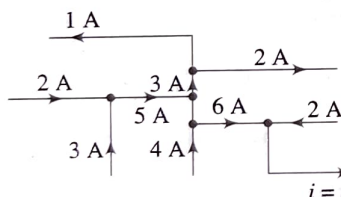
DPP 5.5

Single Correct Answer Type

1. (a) According to Kirchhoff's first law

At junction A, $i_{AB} = 2 + 2 = 4\text{ A}$ At junction B, $i_{AB} = i_{BC} - 1 = 3\text{ A}$ At junction C, $i = i_{BC} - 1.3 = 3 - 1.3 = 1.7\text{ amp}$

2. (b) By using Kirchhoff's junction law as shown below



$$3. (d) \quad i = \frac{E_1 + E_2 + E_3 + \dots + E_n}{(r_1 + r_2 + r_3 + \dots + r_n)}$$

$$= \frac{1.5(r_1 + r_2 + r_3 + \dots + r_n)}{(r_1 + r_2 + r_3 + \dots + r_n)} = 1.5\text{ A}$$

4. (a) The equivalent emf of this combination is given by

$$E_{eq} = \frac{E_1 r_2 + E_2 r_1}{r_1 + r_2}$$

This suggests that the equivalent emf E_{eq} of the two cells is given by

$$E_1 < E_{eq} < E_2$$

5. (b) Let n be the number of wrongly connected cells.Number of cells helping one another $= (12 - n)$ Total e.m.f. of such cells $= (12 - n)E$ Total e.m.f. of cells opposing $= nE$ Resultant e.m.f. of battery $= (12 - n)E - nE = (12 - 2n)E$ Total resistance of cells $= 12r$ $\therefore$ Resistance remains the same irrespective of connections of cells)

With additional cells

(a) Total e.m.f. of cells when additional cells help battery
 $= (12 - 2n)E + 2E$

$$\text{Total resistance} = 12r + 2r = 14r$$

$$\therefore \frac{(12 - 2n)E + 2E}{14r} = 3 \quad (i)$$

(b) Similarly when additional cells oppose the battery

$$\frac{(12 - 2n)E - 2E}{14r} = 2 \quad (ii)$$

Solving (i) and (ii), $n = 1$ 6. (a) Suppose m rows are connected in parallel and each row contains n identical cells (each cell having $E = 15\text{ V}$ and $r = 2\ \Omega$)For maximum current in the external resistance R , the necessary

$$\text{condition is } R = \frac{nr}{m}$$

$$\Rightarrow 12 = \frac{n \times 2}{m} \Rightarrow n = 6m \quad (i)$$

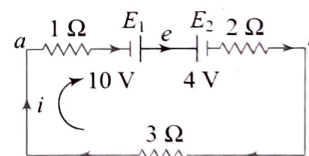
$$\text{Total cells} = 24 = n \times m \quad (ii)$$

On solving equations (i) and (ii), $n = 12$ and $m = 2$ 7. (b) Here internal resistance is given by the slope of graph, i.e., $\frac{x}{y}$

$$\text{But conductance} = \frac{1}{\text{Resistance}} = \frac{y}{x}$$

8. (d) Since $E_1(10\text{ V}) > E_2(4\text{ V})$

So current in the circuit will be clockwise.



Applying Kirchhoff's voltage law

$$-1 \times i + 10 - 4 - 2 \times i - 3i = 0 \Rightarrow i = 1\text{ A (a to b via e)}$$

$$\therefore \text{Current} = \frac{V}{R} = \frac{10 - 4}{6} = 1.0\text{ A}$$

9. (a) Applying Kirchhoff's law

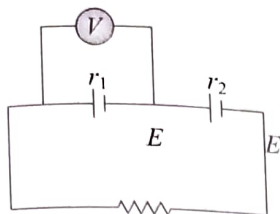
$$(2 + 2) = (0.1 + 0.3 + 0.2)i \Rightarrow i = \frac{20}{3}\text{ A}$$

Hence potential difference across A

$$= 2 - 0.1 \times \frac{20}{3} = \frac{4}{3}\text{ V (less than 2 V)}$$

$$\text{Potential difference across B} = 2 - 0.3 \times \frac{20}{3} = 0$$

11. (b) Let the voltage across any one cell is V , then



$$V = E - ir = E - r_1 \left(\frac{2E}{r_1 + r_2 + R} \right)$$

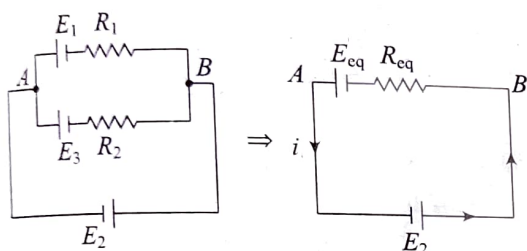
But $V = 0$

$$\Rightarrow E - \frac{2Er_1}{r_1 + r_2 + R} = 0$$

$$\Rightarrow r_1 + r_2 + R = 2r_1$$

$$\Rightarrow R = r_1 - r_2$$

11. (b) The given circuit can be redrawn

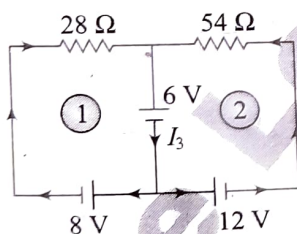


$$E_{eq} = \frac{E_1 R_2 + E_2 R_1}{R_1 + R_2} = \frac{2 \times 4 + 2 \times 4}{4 + 4} = 2 \text{ V and}$$

$$R_{eq} = \frac{4}{2} = 2 \Omega.$$

$$\text{Current } i = \frac{2+2}{2} = 2 \text{ A from A to B through } E_2.$$

12. (d) Suppose current through different paths of the circuit is as follows.



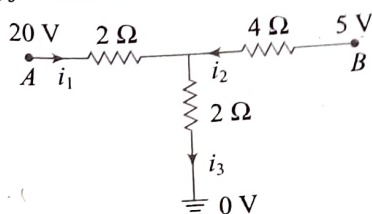
After applying KVL for loop (1) and loop (2)

$$\text{We get } 28I_1 = -6 - 8 \Rightarrow I_1 = -\frac{1}{2} \text{ A}$$

$$\text{and } 54I_2 = -6 - 12 \Rightarrow I_2 = -\frac{1}{3} \text{ A}$$

$$\text{Hence } I_3 = I_1 + I_2 = -\frac{5}{6} \text{ A}$$

13. (a) Let V be the potential of the junction as shown in figure. Applying junction law, we have



$$\text{or } \frac{20-V}{2} + \frac{5-V}{4} = \frac{V-0}{2}$$

$$\text{or } 40 - 2V + 5 - V = 2V \text{ or } 5V = 45 \Rightarrow V = 9 \text{ V}$$

$$\therefore i_3 = \frac{V}{2} = 4.5 \text{ A}$$

Multiple Correct Answers Type

14. (a, b)

According to Kirchhoff's law $i_{CD} = i_2 + i_3$

15. (b, d)

Kirchhoff's junction rule is also known as Kirchhoff's current law which states that the algebraic sum of the currents flowing towards any point in an electric network is zero, i.e., charges are conserved in an electric network.

So, Kirchhoff's junction rule is the reflection of conservation of charge

DPP 5.6

Single Correct Answer Type

1. (d) Potential difference between A and B

$$V_A - V_B = 1 \times 1.5$$

$$\Rightarrow V_A - 0 = 1.5 \text{ V} \Rightarrow V_A = 1.5 \text{ V}$$

Potential difference between B and C

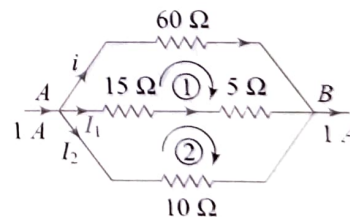
$$V_B - V_C = 1 \times 2.5 - 2.5 \text{ V}$$

$$\Rightarrow 0 - V_C = 2.5 \text{ V} \Rightarrow V_C = -2.5 \text{ V}$$

Potential difference between C and D

$$V_C - V_D = -2 \text{ V} \Rightarrow -2.5 - V_D = -2 \Rightarrow V_D = -0.5 \text{ V}$$

2. (a) Applying Kirchhoff's law in the following figure.



At junction A:

$$i + i_1 + i_2 = 1 \quad (i)$$

For Loop (i)

$$-60i + (15 + 5)i_1 = 0$$

$$\Rightarrow i_1 = 3i \quad (ii)$$

For loop (2)

$$-(15 + 5)i_1 + 10i_2 = 0$$

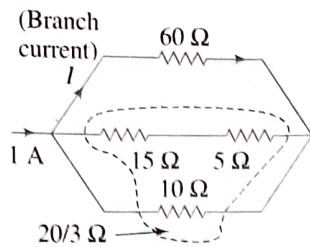
$$\Rightarrow i_2 = i_1 = (3i) = 6i$$

On solving equation (i), (ii) and (iii) we get $i = 0.1 \text{ A}$

Method 2: Branch current =

$$\text{main current} \left(\frac{\text{Resistance of opposite branch}}{\text{Total resistance}} \right)$$

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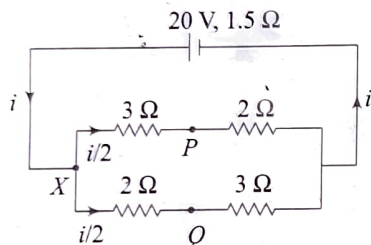


$$\Rightarrow i = 1 \times \left[\frac{\frac{20}{3}}{\frac{20}{3} + 60} \right]$$

$$= 0.1 \text{ A}$$

3. (d) $R_{eq} = \frac{5}{2} \Omega$

$$i = \frac{20}{\frac{5}{2} + 1.5} = 5 \text{ A}$$



Potential difference between X and P,

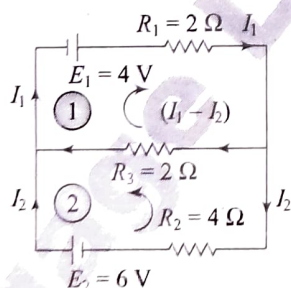
$$V_X - V_P = \left(\frac{5}{2} \right) \times 3 = 7.5 \text{ V}$$

$$V_X - V_Q = \frac{5}{2} \times 2 = 5 \text{ V}$$

On solving (i) and (ii), $V_P - V_Q = -2.5 \text{ V}$; $V_Q > V_P$

4. (b) Applying Kirchhoff's law for the loops (1) and (2) as shown in the figure

For loop (1)



$$-2I_1 - 2(I_1 - I_2) + 4 = 0 \Rightarrow 2I_1 - I_2 = 2 \quad (i)$$

For loop (2)

$$-2(I_1 - I_2) + 4I_2 - 6 = 0 \Rightarrow -I_1 + 3I_2 = 3 \quad (ii)$$

On solving equation, (i) and (ii) $I_1 = 1.8 \text{ A}$

5. (a) In Figure (b) current through $R_2 = I - \frac{I}{10} = \frac{9I}{10}$

Potential difference across $R_2 =$ Potential difference across R

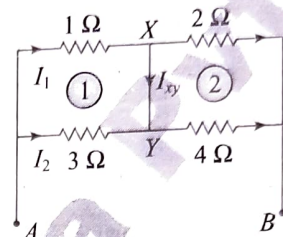
$$\Rightarrow R_2 \times \frac{9}{10} i = R \times \frac{i}{10}, \text{ i.e., } R_2 = \frac{R}{9} = \frac{11}{9} \Omega$$

$$R_{eq} = \frac{R_2 \times R}{(R_2 + R)} = \frac{\frac{11}{9} \times \frac{11}{1}}{\frac{11}{9} + \frac{11}{1}} = \frac{11}{10} \Omega$$

Total circuit resistance,

$$= \frac{11}{10} + R_1 = R = 11 \Rightarrow R_1 = 9.9 \Omega$$

6. (c)



$$-i_1 + 0 \times i_{xy} + 3i_2 = 0, \text{ i.e., } i_1 = 3i_2 \quad (i)$$

$$\text{Also } -2(i_1 - i_{xy}) + 4(i_1 + i_{xy}) = 0$$

$$\Rightarrow 2i_1 - 4i_2 = 6i_{xy} \quad (ii)$$

$$\text{Also } V_{AB} - 1 \times i_1 - 2(i_1 - i_{xy}) = 0 \Rightarrow 50 = i_1 + 2(i_1 - i_{xy})$$

$$= 3i_1 - 2i_{xy} \quad (iii)$$

Solving (i), (ii) and (iii), $i_{xy} = 2 \text{ A}$

7. (d) Let the current in 12Ω resistance be i

Applying loop theorem in closed mesh AEFCA

$$12i = -E + E = 0 \therefore i = 0$$

$$8. (a) \quad V_A - V_O = \frac{1}{4} V = I_1 R_1 \quad (i)$$

$$V_O - V_B = \frac{1}{12} V = I_2 R_2 \quad (ii)$$

$$V_O - V_C = \frac{1}{4} V = I_3 R_3 \quad (iii)$$

$$V_O - V_D = \frac{3}{4} V = I_4 R_4 \quad (iv)$$

$$= (I_1 - I_2 - I_3) R_4$$

Since, $I_1 = I_2 + I_3 + I_4$ (see the voltages)

Let $I_1 = 4I$, $I_2 = 2I$ and $I_3 = I$

$$\text{From equation (i), } \frac{V}{4} = 4I \cdot R_1 \text{ or } R_1 = \frac{V}{16I}$$

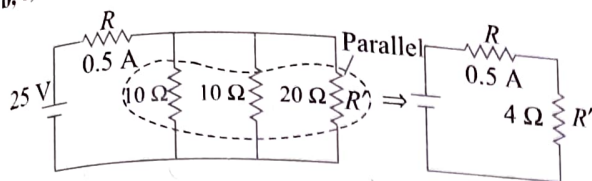
$$\text{Similarly, } R_2 = \frac{V}{24I}, R_3 = \frac{V}{4I}$$

$$\text{From equation (iv), } \frac{3V}{4} = (4I - 2I - I) R_4$$

$$R_4 = \frac{3V}{4I}$$

$$R_1 : R_2 : R_3 : R_4 = \frac{1}{16} : \frac{1}{24} : \frac{1}{4} : \frac{3}{4}$$

$$= 3 : 2 : 12 : 36$$

$q, (a, b, c)$ 

$$\frac{1}{R'} = \frac{1}{10} + \frac{1}{10} + \frac{1}{20} \Rightarrow R' = \frac{20}{5} = 4 \Omega$$

Now using ohm's law $i = \frac{25}{R + R'} \Rightarrow 0.5 = \frac{25}{R + 4}$

$$\Rightarrow R + 4 = \frac{25}{0.5} = 50 \Rightarrow R = 50 - 4 = 46 \Omega$$

$$\text{Current through } 20 \, \Omega \text{ resistor} = \frac{0.5 \times 5}{20 + 5} = \frac{2.5}{25} = 0.1 \, \text{A}$$

= Potential difference across $20\ \Omega = 20 \times 0.1 = 2\text{ V}$

10. (a, d)

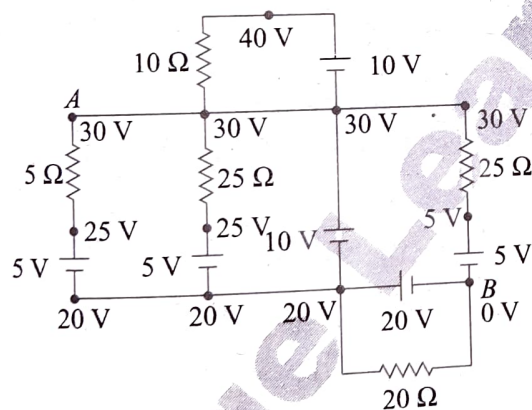
Here, the potential drop is taking place across AB and r . Since the equivalent resistance of parallel combination of R and R' is

always less than R , therefore $I \geq \frac{V}{r+R}$ always.

Comprehension Type

11. (a) 12. (d)

Assume the potential at B to be zero. The potential are given at various points in the circuit.



$$\text{Then } I_1 = \frac{30 - 25}{5} = 1 \text{ A and } I_2 = \frac{30 - 5}{25} = 1 \text{ A}$$

Therefore $\frac{I_1}{I_2} = 1$

Now from the figure, $V_A = 30 \text{ V}$ and $V_B = 0 \text{ V}$.

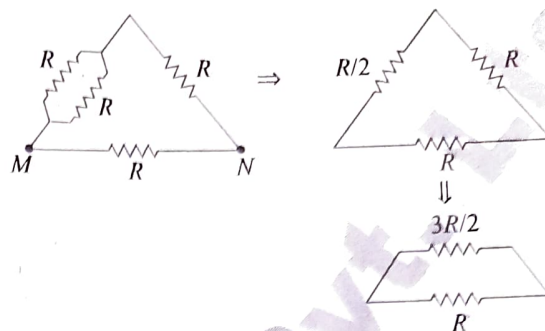
Therefore $V_A - V_B = 30 \text{ V}$

Net power dissipated by resistor is

$$= \frac{(30-25)^2}{5} + \frac{(40-30)^2}{10} + \frac{(30-25)^2}{25}$$

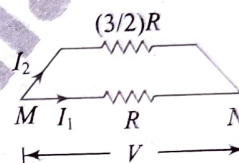
$$= + \frac{(30-5)^2}{25} + \frac{(20)^2}{20} = 61 \text{ W}$$

13. (d) $R_{\text{eq}} = \frac{R \times (3/2)R}{(5/2)R} = \frac{3}{5}R$



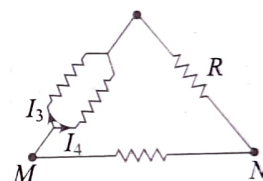
14. (a) $V = I_1 R = I_2 \times \frac{3R}{2}$

$$I_1 = \frac{3}{2} I_2$$



$$I = I_1 + I_2 = \frac{5}{3}I_2$$

$$I_2 = \frac{2}{5}I$$

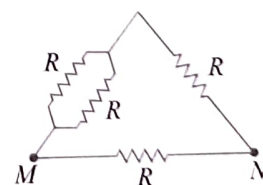


But $I_2 = I_3 + I_4$

So, $I_3 = \frac{I}{5}$

15. (c) If equivalent resistance between M and O is R_{eq}

$$\frac{1}{R_{\text{eq1}}} = \frac{1}{R} + \frac{1}{R} + \frac{1}{2R}$$



$$R_{\text{eq1}} = \frac{2}{5} R$$

If equivalent resistance between O and Q is R_{eq2}

$$\frac{1}{R_{eq2}} = \frac{1}{(3/2)R} + \frac{1}{R}$$

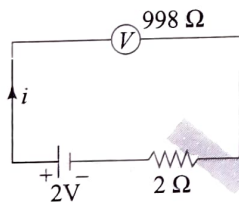
$$R_{eq2} = \frac{3}{2} R$$

$$R_{eq} = R_{eq1} + R_{eq2} = R$$

DPP 6.1

Single Correct Answer Type

1. (c) Equivalent resistance of the circuit $R_{eq} = 100 \Omega$
current through the circuit $i = \frac{2.4}{100} \text{ A}$
PD across combination of voltmeter and 100Ω resistance
 $= \frac{2.4}{100} \times 50 = 1.2 \text{ V}$
Since the voltmeter and 100Ω resistance are in parallel, so the voltmeter reads the same value, i.e., 1.2 V .
2. (d) $S = \frac{i_g G}{(i - i_g)} \Rightarrow \frac{G}{S} = \frac{i - i_g}{i_g} = \frac{10 - 1}{1} = \frac{9}{1}$
3. (d) $R = \frac{V}{i_g} - G = \frac{5}{100/10^3} - 2 = \frac{5000}{100} - 2 = 48 \Omega$
4. (c) $i_g = \frac{iS}{S + G} \Rightarrow 10 = \frac{50 \times 12}{12 + G} \Rightarrow 12 + G = 60 \Rightarrow G = 48 \Omega$
5. (b) $\because i_g = 10\% \text{ of } i = \frac{i}{10} \Rightarrow S = \frac{G}{(n-1)} = \frac{90}{(10-1)} = 10 \Omega$
6. (c) If resistance of ammeter is r , then
 $20 = (R + r)4 \Rightarrow R + r = 5 \Rightarrow R < 5 \Omega$
7. (c) Error in measurement = Actual value - Measured value



Actual value = 2 V

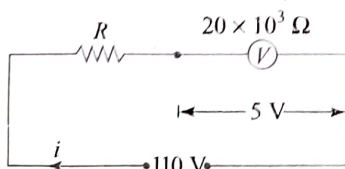
$$i = \frac{2}{998 + 2} = \frac{1}{500} \text{ A}$$

$$\text{Since } E = V + ir \Rightarrow V = E - ir = 2 - \frac{1}{500} \times 2 = \frac{998}{500} \text{ V}$$

$$\therefore \text{Measured value} = \frac{998}{500} \text{ V}$$

$$\Rightarrow \text{Error} = 2 - \frac{998}{500} = 4 \times 10^{-3} \text{ V}$$

8. (c)



$$\text{Here } i = \frac{110}{20 \times 10^3 + R}$$

$$\therefore V = iR \Rightarrow 5 = \left(\frac{110}{20 \times 10^3 + R} \right) \times 20 \times 10^3$$

$$\Rightarrow 10^2 + 5R = 22 \times 10^5 \Rightarrow R = 21 \times \frac{10^5}{5} = 420 \text{ k}\Omega$$

$$9. (c) \text{ Total resistance of the circuit} = \frac{80}{2} + 20 = 60 \Omega$$

$$\Rightarrow \text{Main current } i = \frac{2}{60} = \frac{1}{30} \text{ A}$$

Combination of voltmeter and 80Ω resistance is connected in series with 20Ω , so current through 20Ω and this combination will be the same $= \frac{1}{30} \text{ A}$.

Since the resistance of voltmeter is also 80Ω , so this current is equally distributed in 80Ω resistance and voltmeter (i.e. $\frac{1}{60} \text{ A}$ through each)

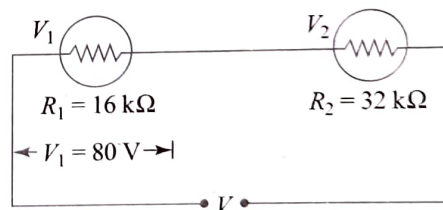
$$\text{PD across } 80 \Omega \text{ resistance} = \frac{1}{60} \times 80 = 1.33 \text{ V}$$

$$10. (a) (R + G)i_g = V \Rightarrow (R + G) = \frac{V}{i_g} = \frac{3}{30 \times 16 \times 10^{-6}} = 6.25 \text{ k}\Omega$$



$\therefore$ Value of R is nearly equal to $6 \text{ k}\Omega$
This is connected in series in a voltmeter.

11. (d)



$$R_1 = 80 \times 200 = 16000 \Omega = 16 \text{ k}\Omega$$

Current flowing through V_1 = Current flowing through V_2

$$= \frac{80}{16 \times 10^3} = 5 \times 10^{-3} \text{ A}$$

So, potential differences across V_2 is

$$V_2 = 5 \times 10^{-3} \times 32 \times 10^3 = 160 \text{ V}$$

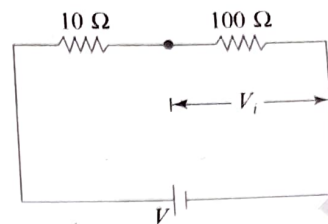
Hence, line voltage $V = V_1 + V_2 = 80 + 160 = 240 \text{ V}$

12. (d) For conversion of galvanometer (of resistances) into voltmeter, a resistance R is connected in series.

$$\therefore i_g = \frac{V_1}{R + G} \text{ and } i_g = \frac{V_2}{2R + G}$$

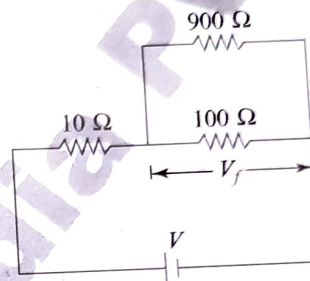
$$\Rightarrow \frac{V_1}{R+G} = \frac{V_2}{2R+G} \Rightarrow \frac{V_2}{V_1} = \frac{2R+G}{R+G} = \frac{2(R+G)-G}{(R+G)}$$

$$= 2 - \frac{G}{(R+G)} \Rightarrow V_2 = 2V_1 - \frac{V_1 G}{(R+G)} \Rightarrow V_2 < 2V_1$$



Finally after connecting voltmeter across 100 Ω , equivalent resistance $\frac{100 \times 900}{(100 + 900)} = 90 \Omega$

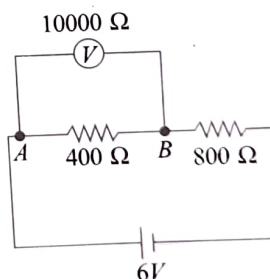
Final potential difference,



$$V_f = \frac{90}{(90 + 10)} \times V = \frac{9}{10} V$$

$$\% \text{ error} = \frac{V_i - V_f}{V_i} \times 100 = \frac{\frac{10}{11} V - \frac{9}{10} V}{\frac{10}{11} V} \times 100 = 1.0$$

4. (d) Before connecting voltmeter potential difference across 400 Ω resistance is



$$V_i = \frac{400}{(400 + 800)} \times 6 = 2 \text{ V}$$

After connecting voltmeter equivalent resistance between A and

$$B = \frac{400 \times 10,000}{(400 + 10,000)} = 384.6 \Omega$$

Hence, potential difference measured by voltmeter

$$V_f = \frac{384.6}{(384.6 + 800)} \times 6 = 1.95 \text{ V}$$

$$\text{Error in measurement} = V_i - V_f = 2 - 1.95 = 0.05 \text{ V}$$

$$5. (c) \frac{i}{i_g} = 1 + \frac{G}{S} \Rightarrow \frac{5}{0.05} = 1 + \frac{50}{S}$$

$$\Rightarrow S = \frac{50}{99} = \frac{\rho \times l}{A} \Rightarrow l = \frac{50}{99} \times \frac{2.97 \times 10^{-2} \times 10^{-4}}{5 \times 10^{-7}} = 3 \text{ m}$$

$$6. (d) \text{ Resistance between A and B} = \frac{1000 \times 500}{(1500)} = \frac{1000}{3}$$

$$13. (b) \frac{i_g}{i} = \frac{S}{G + S} \Rightarrow i_g G = (i - i_g) S$$

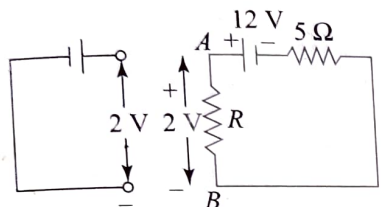
$$\therefore i_g G = (0.03 - i_g) 4r$$

$$\text{and } i_g G = (0.06 - i_g) r$$

From (i) and (ii)

$$0.12 - 4i_g = 0.06 - i_g \Rightarrow i_g = 0.02 \text{ A}$$

14. (a)



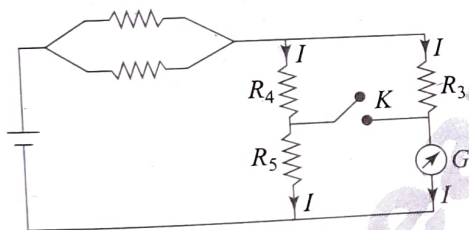
If potential drop between A and B is also 2 V, then no current will pass through the galvanometer.

$$\text{Potential drop across } R = \left(\frac{12}{R + 5} \right) R = 2$$

$$12R = 2R + 10$$

$$R = 1 \Omega$$

15. (c) If the reading of galvanometer does not change, then Wheatstone bridge with R_3, R_4, R_5, G and key K is balanced.



$$I(R_4) = I(R_5)$$

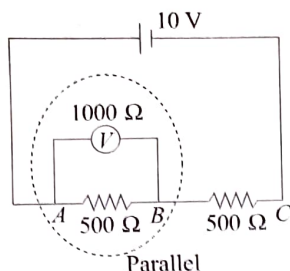
$$\text{and } I(R_3) = I_G$$

DPP 6.2

Single Correct Answer Type

- (d) If the voltmeter is ideal, then given circuit is an open circuit, so reading of voltmeter is equal to the e.m.f. of cell, i.e., 6 V.
- (d) After connecting a resistance R in parallel with voltmeter, its effective resistance decreases. Hence less voltage appears across it, i.e., V will decrease. Since overall resistance decreases so more current will flow, i.e., A will increase.
- (c) Before connecting the voltmeter, potential difference across 100 Ω resistance

$$V_i = \frac{100}{(100 + 10)} \times V = \frac{10}{11} V$$



So, equivalent resistance of the circuit

$$R_{eq} = 500 + \frac{1000}{3} = \frac{2500}{3}$$

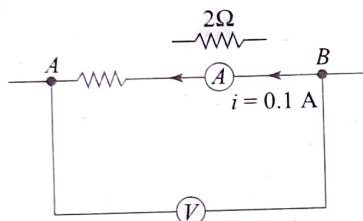
∴ Current drawn from the cell

$$i = \frac{10}{(2500/3)} = \frac{3}{250} \text{ A}$$

Reading of voltmeter, i.e.,

$$\text{potential difference across } AB = \frac{3}{250} \times \frac{1000}{3} = 4 \text{ V}$$

7. (a) According to following figure,



Reading of voltmeter = Potential difference between A and B
 $= i(R + 2) \Rightarrow 12 = 0.1(R + 2) \Rightarrow R = 118 \Omega$

8. (b) In series: Potential difference $\propto R$

$$\text{When only } S_1 \text{ is closed } V_1 = \frac{3}{4}E = 0.75E$$

$$\text{When only } S_2 \text{ is closed } V_2 = \frac{6}{7}E = 0.86E$$

and when both S_1 and S_2 are closed combined resistance of $6R$ and $3R$ is $2R$

$$\therefore V_3 = \left(\frac{2}{3}\right)E = 0.67E \Rightarrow V_2 > V_1 > V_3$$

9. (b) Voltage sensitivity = $\frac{\text{Current sensitivity}}{\text{Resistance of galvanometer } G}$

$$\Rightarrow G = \frac{10}{2} = 5 \Omega$$

$$\text{Here } I_g = \text{Full-scale deflection current} = \frac{150}{10} = 15 \text{ mA}$$

$$V = \text{Voltage to be measured} = 150 \times 1 = 150 \text{ V}$$

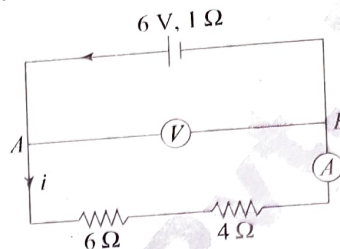
$$\text{Hence } R = \frac{V}{i_g} - G = \frac{150}{15 \times 10^{-3}} - 5 = 9995 \Omega$$

10. (d) For conversion of a galvanometer into a voltmeter

$$\frac{V}{R + G} = i_g \Rightarrow \frac{V}{R_V} = i_g, \text{ where } R_V = R + G = \text{Total resistance}$$

$$\Rightarrow R_V = \frac{V}{i_g} \Rightarrow R_V \propto V$$

11. (b) To make range n times, the galvanometer resistance should be G/n , where G is the initial resistance.
12. (c) The given circuit can be redrawn as follows



$$\text{Current } i = \frac{6}{6 + 4 + 1} = \frac{6}{11} \text{ A}$$

$$\text{P.D. between A and B, } V = \frac{6}{11} \times 10 = \frac{60}{11} \text{ V}$$

13. (b) Current flowing in the circuit $i = \frac{E}{R} = \frac{10 - 4}{20 + 10} = \frac{1}{5} \text{ A}$

$$\text{P.D. across } AC = \frac{1}{5} \times 20 = 4 \text{ V}$$

$$\text{P.D. across } AN = 4 + 4 = 8 \text{ V}$$

14. (b) Voltage sensitivity = $\frac{\text{Current sensitivity}}{\text{Resistance of galvanometer } G}$

$$\Rightarrow G = \frac{10}{2} = 5 \Omega$$

$$\text{Here } i_g = \text{Full scale deflection current} = \frac{150}{10} = 15 \text{ mA}$$

$$V = \text{Voltage to be measured} = 150 \times 1 = 150 \text{ V}$$

$$\text{Hence } R = \frac{V}{i_g} - G = \frac{150}{15 \times 10^{-3}} - 5 = 9995 \Omega$$

DPP 6.3

Subjective Type

1. The null point is obtained only when emf of primary cell is less than the potential difference across the wires of potentiometer. Let R be the resistance of the potentiometer wire. Effective resistance of potentiometer and variable resistor ($R = 50 \Omega$) is given by $= 50 \Omega + R'$. Effective voltage applied across potentiometer = 10 V.

The current through the main circuit,

$$I = \frac{V}{50 \Omega + R} = \frac{10}{50 \Omega + R}$$

Potential difference across wire of potentiometer:

Since with 50Ω resistor, null point is not obtained. It is possible only when

$$\frac{10 \times R'}{50 \times R} < 8$$

$$\Rightarrow 10R' < 400 + 8R'$$

$$2R' < 400 \text{ or } R' < 200 \Omega$$

Similarly with 10Ω resistor, null point is not obtained. It is possible only when

$$\frac{10 \times R'}{10 + R'} > 8$$

$$\Rightarrow 2R' > 80$$

$$\Rightarrow R' > 40$$

$$\frac{10 \times \frac{3}{4}R'}{10 + R'} < 8$$

$$\Rightarrow 7.5R' < 80 + 8R'$$

$$R' > 160$$

$$\Rightarrow 160 < R' < 200$$

Any R' between 160Ω and 200Ω will achieve.

Since, the null point on the last (4^{th}) segment of the potentiometer, therefore potential drop across 400 cm of wire $> 8 \text{ V}$.

This imply that potential gradient

$$k \times 400 \text{ cm} > 8 \text{ V}$$

$$\text{or } k \times 4 \text{ m} < 8 \text{ V}$$

$$k > 2 \text{ V/m}$$

Similarly, potential drop across 300 cm wire $< 8 \text{ V}$.

$$k \times 300 \text{ cm} < 8 \text{ V}$$

$$\text{or } k \times 4 \text{ m} > 8 \text{ V}$$

$$k < 2 \frac{2}{3} \text{ V/m}$$

$$\text{Thus, } 2 \frac{2}{3} \text{ V/m} > k > 2 \text{ V/m}$$

2. In potentiometer, the thick metallic strips are used as they have negligible resistance and need not to be counted in the length l_1 of the null point of potentiometer. It is for the convenience of experimenter as he measures only their lengths along the straight wires each of lengths 1 m .

This measurement is done with the help of centimetre scale or metre scale with accuracy.

3. With the increase of R , the current in main circuit decreases which, in turn, decreases the potential difference across AB and hence potential gradient (k) across AB decreases.

Since, at neutral point, for given emf of cell, l increases as potential gradient (k) across AB has decreased because

$$E = kl$$

Thus, with the increase of l , the balance point neutral point will shift towards B .

4. (a) The deflection in galvanometer is one sided and the deflection decreased, while moving from one end A of the wire to the end B , thus implying that current in auxiliary circuit (lower circuit containing primary cell) decreases, while potential difference across A and jockey increases.

This is possible only when positive terminal of the cell E_1 is connected at X and $E_1 > E$.

- (b) The deflection in galvanometer is one sided and the deflection increased, while moving from one end A of the wire to the end B , this implies that current in auxiliary circuit (lower circuit containing primary cell) increases, while potential difference across A and jockey increases.

This is possible only when negative terminal of the cell E_1 is connected at X .

5. (a) Current in primary circuit,

$$i_p = \frac{10}{(1000 + R)}$$

where R is resistance of potentiometer wire
So, potential gradient,

$$x = \frac{10R(50 \text{ cm})}{(1000 + R)(100 \text{ cm})} \text{ V/cm}$$

$$\text{Now } \varepsilon = x(50 \text{ cm}) = \frac{10R(50 \text{ cm})}{(1000 + R)(100 \text{ cm})} \quad (1)$$

When area of cross-section is doubled, then resistance will become half. So,

$$\varepsilon = \frac{10(R/2)(75 \text{ cm})}{(1000 + R/2)(100 \text{ cm})} \quad (2)$$

Dividing (1) and (2)

$$1 = \frac{10R}{2(1000 + R)} \cdot \frac{(2000 + R)}{10R} \left(\frac{4}{3} \right)$$

$$\Rightarrow 4000 + 2R = 3000 + 3R \quad \text{So } R = 1000 \Omega$$

$$\text{So from (1) we get } \varepsilon = \frac{10 \times 1000}{2000 \times 2} = \frac{10}{4} \text{ V} = 2.5 \text{ V}$$

$$(b) \text{ Now } R = \rho \frac{l}{A}. \text{ Hence } \rho = \frac{RA}{l}$$

$$= \frac{1000 \times 100 \times 10^{-4}}{100 \times 10^{-2}} \Omega\text{-m}$$

$$\text{So, } \rho = 10 \Omega\text{-m}$$

Single Correct Answer Type

6. (b) In balance condition, potentiometer doesn't take the current from secondary circuit.
7. (d) Balance point has some fixed position on potentiometer wire. It is not affected by the addition of resistance between balance point and cell.
8. (d) The emf of the standard cell must be greater than that of experimental cells, otherwise balance point is not obtained.

9. (a) $E \propto l$ (balancing length)

$$10. (b) E = xl = \frac{V}{l} = \frac{iR}{L} \times l \Rightarrow E = \frac{e}{(R + R_h + r)} \times \frac{R}{L} \times l$$

$$\Rightarrow E = \frac{10}{(5 + 4 + 1)} \times \frac{5}{5} \times 3 = 3 \text{ V}$$

11. (a) From the principle of potentiometer $V \propto l$

$$\Rightarrow \frac{V}{E} = \frac{l}{L} \text{ where } V = \text{emf of battery, } E = \text{emf of standard cell,}$$

L = Length of potentiometer wire

$$\frac{V}{E} = \frac{El}{L} = \frac{30E}{100}$$

$$12. (a) \text{ Potential gradient } x = \frac{e}{(R + R_h + r)} \cdot \frac{R}{L}$$

$$\Rightarrow \frac{0.2 \times 10^{-3}}{10^{-2}} = \frac{2}{(R + 490 + 0)} \times \frac{R}{1} \Rightarrow R = 4.9 \Omega$$

13. (a) The voltage per unit length of the metre wire PQ is $\left(\frac{6.00 \text{ mV}}{0.600 \text{ m}}\right)$, i.e., 10 mV/m . Hence potential difference across the metre wire is $10 \text{ mV/m} \times 1 \text{ m} = 10 \text{ mV}$. The current drawn from the driver cell is $i = \frac{10 \text{ mV}}{5 \Omega} = 2 \text{ mA}$. The resistance $R = \frac{(2 \text{ V} - 10 \text{ mV})}{2 \text{ mA}} = \frac{1990 \text{ mV}}{2 \text{ mA}} = 995 \Omega$.

14. (b) In a potentiometer experiment, the emf of a cell can be measured, if the potential drop along the potentiometer wire is more than the emf of the cell to be determined. Here, values of emfs of two cells are given as 5 V and 10 V ; therefore, the potential drop along the potentiometer wire must be more than 10 V .

DPP 6.4

Subjective Type

1. The advantage of null point method in a Wheatstone bridge is that the resistance of galvanometer does not affect the balance point, there is no need to determine current in resistances and the internal resistance of a galvanometer.

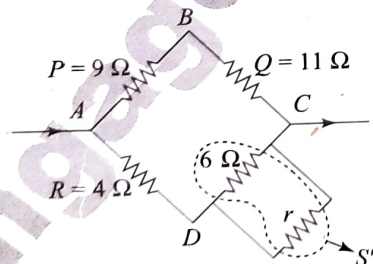
It is easy and convenient method for observer.

The R_{unknown} can be calculated applying Kirchhoff's rules to the circuit. We would need additional accurate measurement of all the currents in resistances and galvanometer and internal resistance of the galvanometer.

Single Correct Answer Type

2. (a) In meter bridge experiment, it is assumed that the resistance of the L shaped plate is negligible, but actually it is not so. The error created due to this is called end error. To remove this the resistance box and the unknown resistance must be interchanged and then the mean reading must be taken.

3. (c) $\frac{P}{Q} = \frac{R}{S'}$ (For balancing bridge)



$$\Rightarrow S' = \frac{4 \times 11}{9} = \frac{44}{9}$$

$$\Rightarrow \frac{1}{S'} = \frac{1}{r} + \frac{1}{6}$$

$$\Rightarrow \frac{9}{44} - \frac{1}{6} = \frac{1}{r}$$

$$\Rightarrow r = \frac{132}{5} = 26.4 \Omega$$

4. (b) In the part $c b d$,

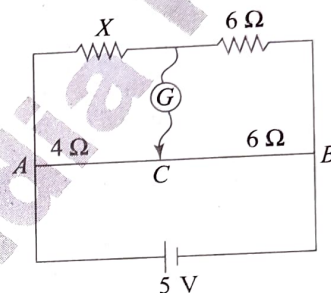
$$V_c - V_b = V_b - V_d \Rightarrow V_b = \frac{V_c + V_d}{2}$$

In the part $c a d$,

$$V_c - V_a > V_a - V_d \Rightarrow \frac{V_c + V_d}{2} > V_a \Rightarrow V_b > V_a$$

5. (c) In balance condition, no current will flow through the branch containing S .

6. (c)



Resistance of the part AC

$$R_{AC} = 0.1 \times 40 = 4 \Omega \text{ and } R_{CB} = 0.1 \times 60 = 6 \Omega$$

In balanced condition $\frac{X}{6} = \frac{4}{6} \Rightarrow X = 4 \Omega$

Equivalent resistance $R_{eq} = 5 \Omega$ so current drawn from battery

$$i = \frac{5}{5} = 1 \text{ A}$$

7. (a) In balancing condition, $\frac{R_1}{R_2} = \frac{l_1}{100 - l_1}$

$$\Rightarrow \frac{X}{Y} = \frac{20}{80} = \frac{1}{4}$$

$$\text{and } \frac{4X}{Y} = \frac{l}{100 - l}$$

$$\Rightarrow \frac{4}{4} = \frac{l}{100 - l} \Rightarrow l = 50 \text{ cm}$$

8. (c) Let S be larger and R be smaller resistances connected in two gaps of meter bridge.

$$\therefore S = \left(\frac{100 - l}{l}\right) R = \frac{100 - 20}{20} R = 4R$$

When 15Ω resistance is added to resistance R , then

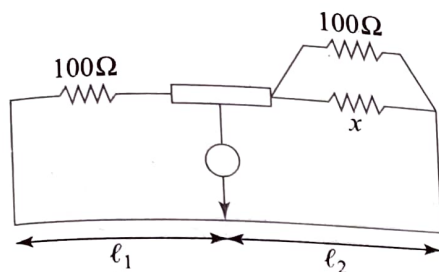
$$S = \left(\frac{100 - 40}{40}\right) (R + 15) = \frac{6}{4} (R + 15)$$

From equations (i) and (ii), $R = 9 \Omega$

9. (b) Wheatstone bridge is in balanced condition

$$\text{So } \frac{100}{l_1} = \frac{100 + x}{l_2}$$

$$\therefore \frac{l_1}{l_2} = 2 \Rightarrow x = 100 \Omega$$



10. (c) The percentage error in R can be minimised by adjusting the balance point near the middle of the bridge, i.e., when l_1 is close to 50 cm. This requires a suitable choice of S .

$$\text{Since } \frac{R}{S} = \frac{Rl_1}{R(100 - l_1)} = \frac{l_1}{100 - l_1}$$

Since here, $R : S :: 2.9 : 97.1$ imply that the S is nearly 33 times to that of R . In order to make this ratio 1:1, it is necessary to reduce the value of S nearly $\frac{1}{33}$ times i.e., nearly 3Ω .

11. (b) When the resistance of all four arms of the bridge is the same, most sensitive will be the slide wire bridge. The best option is (b).
 12. (a) Balancing length is independent of the cross sectional area of the wire.
 13. (a) Reading of galvanometer remains the same whether switch S is opened or closed, hence no current will flow through the switch, i.e., R and G will be in series and the same current will flow through them. $I_R = I_G$.

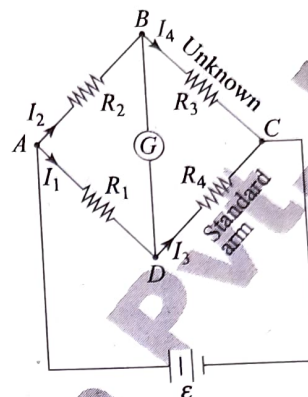
Multiple Correct Answers Type

14. (b, c)

Given, for first student, $R_2 = 10 \Omega$, $R_1 = 5 \Omega$, $R_3 = 5 \Omega$
 For second student, $R_1 = 500 \Omega$, $R_3 = 5 \Omega$

Now, according to Wheatstone bridge rule,

$$\frac{R_2}{R} = \frac{R_1}{R_3} \Rightarrow R = R_3 \times \frac{R_2}{R_1} \quad (i)$$



Now putting all the values in Eq. (i), we get $R = 10 \Omega$ for both students. Thus, we can analyse that the Wheatstone bridge is most sensitive and accurate if resistances are of the same value.

Thus, the errors of measurement of the two students depend on the accuracy and sensitivity of the bridge, which in turn depends on the accuracy with which R_2 and R_1 can be measured.

When R_2 and R_1 are larger, the currents through the arms of bridge is very weak. This can make the determination of null point accurately more difficult.

15. (a, c)

At neutral point, potential at B and neutral point are the same. When jockey is placed at to the right of D , the potential drop across AD is more than potential drop across AB , which brings the potential of point D less than that of B , hence current flows from B to D .

CHAPTER 7

DPP 7.1

Single Correct Answer Type

1. (d) $U \propto i^2$, hence the graph between U and i is parabolic in nature and should be above graph (b).
 2. (a) In series, $P \propto R$ (i is the same), i.e., in series fine wire (high R) liberates more energy.

In parallel, $P \propto \frac{1}{R}$ (V is the same), i.e., thick wire (less R) liberates more energy.

3. (a) Equivalent resistance in the second case $= R_1 + R_2 = R$

Now, we know that $P \propto \frac{1}{R}$

Since in the second case the resistance ($R_1 + R_2$) is higher than that in the first case (R_1).

Therefore power dissipation in the second case will be decreased.

4. (b) Resistance of 25 W bulb $= \frac{220 \times 220}{25} = 1936 \Omega$

Its safe current $= \frac{220}{1936} = 0.11 \text{ A}$

Resistance of 100 W bulb $= \frac{220 \times 220}{100} = 484 \Omega$

Its safe current $= \frac{220}{484} = 0.48 \text{ A}$

When connected in series to 440 V supply, then the current

$$I = \frac{440}{(1936 + 484)} = 0.18 \text{ A}$$

Thus current is greater for 25 W bulb, so it will fuse.

5. (b) $R = \frac{V^2}{P} \Rightarrow R_1 = \frac{200 \times 200}{100} = 400 \Omega$ and

$$R_2 = \frac{100 \times 100}{200} = 50 \Omega. \text{ Maximum current rating } i = \frac{P}{V}$$

$$\text{So } i_1 = \frac{100}{200} \text{ and } i_2 = \frac{200}{100} \Rightarrow \frac{i_1}{i_2} = \frac{1}{4}$$

6. (a) $\frac{R_1}{R_2} = \frac{P_2}{P_1} = \frac{100}{40} = \frac{5}{2}$. Resistance of 40 W bulb is $\frac{5}{2}$ times than

100 W. In series, $P = i^2 R$ and in parallel, $P = \frac{V^2}{R}$. So 40 W in

series and 100 W in parallel will glow brighter.

7. (a) Resistance R_1 of 500 W bulb $= \frac{(220)^2}{500}$

$$\text{Resistance } R_2 \text{ of 200 W bulb} = \frac{(220)^2}{200}$$

When joined in parallel, the potential difference across both the bulbs will be the same.

$$\text{Ratio of heat produced} = \frac{V^2/R_1}{V^2/R_2} = \frac{R_2}{R_1} = \frac{5}{2}$$

When joined in series, the same current will flow through both the bulbs.

$$\text{Ratio of heat produced} = \frac{i^2 R_1}{i^2 R_2} = \frac{R_1}{R_2} = \frac{2}{5}$$

8. (d) $R_1 = \rho \frac{l_1}{A_1}$ and $R_2 = \rho \frac{l_2}{A_2} \Rightarrow \frac{R_1}{R_2} = \frac{l_1}{l_2} \cdot \frac{A_2}{A_1} = \frac{l_1}{l_2} \left(\frac{r_2}{r_1} \right)^2$

$$\text{Given } \frac{l_1}{l_2} = \frac{1}{2} \text{ and } \frac{r_1}{r_2} = \frac{2}{1} \text{ or } \frac{r_2}{r_1} = \frac{1}{2} \Rightarrow \frac{R_1}{R_2} = \frac{1}{8}$$

$$\therefore \text{Ratio of heat } \frac{H_1}{H_2} = \frac{V^2/R_1}{V^2/R_2} = \frac{R_2}{R_1} = \frac{8}{1}$$

9. (c) $\frac{H}{t} = P = \frac{V^2}{R} \Rightarrow P \propto \frac{1}{R}$ also $R \propto \frac{l}{A} \propto \frac{l^2 \rho}{A \cdot l \rho}$

$$\Rightarrow R \propto \frac{l^2}{m} \Rightarrow R \propto l^2 \text{ (for the same mass)}$$

$$\text{So } \frac{P_A}{P_B} = \frac{l_B^2}{l_A^2} = \frac{4}{1} \Rightarrow P_A = 20 \text{ W}$$

10. (a) In parallel $\frac{1}{t_p} = \frac{1}{t_1} + \frac{1}{t_2} \Rightarrow \frac{1}{t_p} = \frac{t_1 t_2}{t_1 + t_2}$

$$= \frac{5 \times 10}{5 + 10} = \frac{50}{15} = 3.33 \text{ min} = 3 \text{ min } 20 \text{ sec}$$

11. (d) In series $\frac{1}{P_s} = \frac{1}{P_1} + \frac{1}{P_2}$

$$\Rightarrow \frac{1}{(H_s/t_s)} = \frac{1}{(H_1/t_1)} + \frac{1}{(H_2/t_2)}$$

$$\therefore H_s = H_1 = H_2 \text{ So } t_s = t_1 + t_2 = 6 + 3 = 9 \text{ min}$$

12. (c) If resistance does not vary with temperature, P consumed

$$= \left(\frac{V_A}{V_R} \right)^2 \times P_R = \left(\frac{110}{220} \right)^2 \times 100 = 25 \text{ W. But in second cases}$$

resistance decreases so consumed power will be more than 25 W.

$$13. (c) P = \frac{V^2}{R}$$

$$\therefore R = \frac{V^2}{P} \text{ or } R \propto V^2, \text{ i.e., } \frac{R_1}{R_2} = \left(\frac{200}{300}\right)^2 = \frac{4}{9}$$

When connected in series potential drop and power consumed

$$\text{are in the ratio of their resistances. So, } \frac{R_1}{R_2} = \frac{V_1}{V_2} = \frac{R_1}{R_2} = \frac{4}{9}$$

Multiple Correct Answers Type

14. (a, d)

$R_{\text{steel}} = 2R_{\text{Al}}$. In series $H \propto R$ (i is the same)

So, H will be more in steel wire.

In parallel $H \propto \frac{1}{R}$ (V is the same), so H will be more in aluminium wire.

DPP 7.2

Subjective Type

1. Power consumption in a day, i.e., in 5 = 10 units
 Or power consumption per hour = 2 units
 Or power consumption = 2 units = 2 kW = 2000 J/s
 Also, we know that power consumption in resistor,
 $P = V \times I$
 $\Rightarrow 2000 \text{ W} = 220 \text{ V} \times I \text{ or } I \approx 9 \text{ A}$

Now, the resistance of wire is given by $R = \rho \frac{l}{A}$

where A is cross-sectional area of conductor.

Power consumption in the first current carrying wire is given by

$$P = I^2 R$$

$$\rho \frac{l}{A} I^2 = 1.7 \times 10^{-8} \times \frac{10}{\pi \times 10^{-6}} \times 81 \text{ J/s} \approx 4 \text{ J/s}$$

The fractional loss due to the joule heating in first wire

$$= \frac{4}{2000} \times 100 = 0.2\%$$

$$\text{Power loss in Al wire} = 4 \frac{\rho_{\text{Al}}}{\rho_{\text{Cu}}} = 1.6 \times 4 = 6.4 \text{ J/s}$$

The fractional loss due to the joule heating in second wire =

$$\frac{6.4}{2000} \times 100 = 0.32\%$$

2. The power consumption in transmission lines is given by $P = I^2 R_c$, where R_c is the resistance of transmission lines. The power is given by

$$P = VI$$

The given power can be transmitted in two ways namely (i) at low voltage and high current or (ii) high voltage and low current. In power transmission at low voltage and high current more power is wasted as $P \propto I^2$, whereas power transmission at high voltage and low current facilitates the power transmission with minimal power wastage.

The power wastage can be reduced by transmitting power at high voltage.

Single Correct Answer Type

3. (b) The filament of the heater reaches its steady resistance when the heater reaches its steady temperature, which is much higher than the room temperature. The resistance at room temperature is thus much lower than the resistance at its steady state. When the heater is switched on, it draws a larger current than its steady state current. As the filament heats up, its resistance increases and current falls to steady state value.

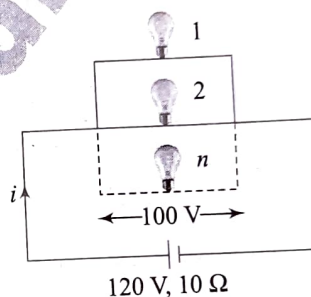
4. (d) Thermal energy in resistor is $U = i^2 R t$
 where $R = R_0(1 + \alpha t) \Rightarrow U = i^2 R_0(1 + \alpha t)t = i^2 R_0 t + i^2 R_0 \alpha t^2$

$$\text{So } \frac{dU}{dt} = i^2 R_0(1 + \alpha t)$$

With the time temperature increases, hence dU/dt increases. This is best shown by curve (d).

5. (c) When each bulb is glowing at full power,

$$\text{Current from each bulb} = i' = \frac{50}{100} = \frac{1}{2} \text{ A}$$



$$\text{So main current } i = \frac{n}{2} \text{ A}$$

$$\text{Also } E = V + ir \Rightarrow 120 = 100 + \left(\frac{n}{2}\right) \times 10 \Rightarrow n = 4$$

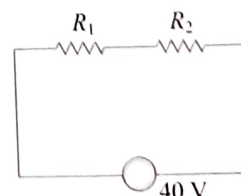
6. (d) Bulb (I): Rated current $I_1 = \frac{P}{V} = \frac{40}{220} = \frac{2}{11} \text{ A}$

$$\text{Resistance } R_1 = \frac{V^2}{P} = \frac{(220)^2}{40} = 1210 \Omega$$

$$\text{Bulb (II): Rated current } I_2 = \frac{100}{220} = \frac{5}{11} \text{ A}$$

$$\text{Resistance } R_2 = \frac{(220)^2}{100} = 484 \Omega$$

When both are connected in series across 40 V supply



Total current through supply

$$I = \frac{40}{R_1 + R_2} = \frac{40}{1210 + 484} = \frac{40}{1694} \approx 0.024 \text{ A}$$

5.54 Electrostatics and Current Electricity

This current is less than the rated current of each bulb. So neither bulb will fuse.

7. (a) $P = \frac{V^2}{R} \Rightarrow P \propto \frac{1}{R}$ ($V = \text{constant}$)

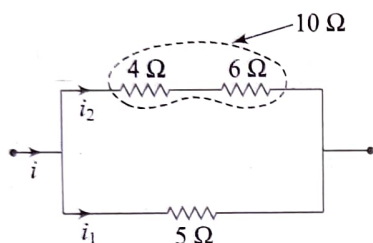
$\therefore$ When one bulb will fuse out, resistance of the series combination will be reduced.

Hence from $P_{\text{Consumed}} \propto \frac{1}{R}$ illumination will increase.

8. (a) Resistance $\propto \frac{1}{\text{power}}$. Thus, 40 W bulb has a high resistance.

Because of which there will be more potential drop across 40 W bulb. Thus 40 W bulb will glow brighter.

9. (b) $\frac{i_1}{i_2} = \frac{R_2}{R_1} = \frac{10}{5} = 2$



Also heat produced per sec, i.e., $\frac{H}{t} = P = i^2 R$

$$\Rightarrow \frac{P_5}{P_4} = \left(\frac{i_1}{i_2}\right)^2 \times \frac{5}{4} = \left(\frac{2}{1}\right)^2 \times \frac{5}{4} = \frac{5}{1} \Rightarrow P_4 = \frac{10}{5} = 2 \text{ cal/sec}$$

10. (c) $H = \frac{V^2}{R} t$

Since supply voltage is the same and equal amount of heat will produce, therefore

$$\frac{R_1}{t_1} = \frac{R_2}{t_2} \text{ or } \frac{R_1}{R_2} = \frac{t_1}{t_2} \quad (i)$$

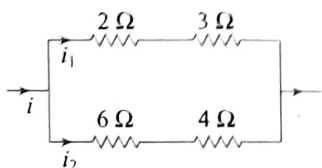
$$\text{But } R \propto l \Rightarrow \frac{R_1}{R_2} = \frac{l_1}{l_2} \quad (ii)$$

$$\text{By (i) and (ii), } \frac{l_1}{l_2} = \frac{t_1}{t_2} \quad (iii)$$

$$\text{Now } l_2 = \frac{2}{3} l_1 \Rightarrow \frac{l_1}{l_2} = \frac{3}{2}$$

$$\therefore \text{By equation (iii), } \frac{3}{2} = \frac{15}{t_2} \Rightarrow t_2 = 10 \text{ minutes}$$

11. (d)



Resistance of upper branch $R_1 = 2 + 3 = 5 \Omega$

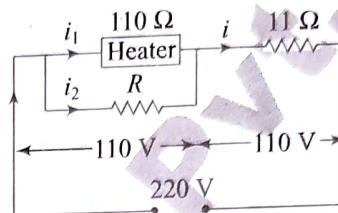
Resistance of lower branch $R_2 = 6 + 4 = 10 \Omega$

$$\text{Hence } \frac{i_1}{i_2} = \frac{R_2}{R_1} = \frac{10}{5} = 2$$

$$\frac{\text{Heat generated across } 3 \Omega (H_1)}{\text{Heat generated across } 6 \Omega (H_2)} = \frac{i_1^2 \times 3}{i_2^2 \times 6} = \frac{4}{2} = 2$$

$\therefore$ Heat generated across $3 \Omega = 120 \text{ cal/sec}$

12. (a) Power consumed by heater is 110 W so by using $P = \frac{V^2}{R}$



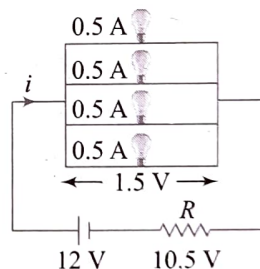
$$110 = \frac{V^2}{110} \Rightarrow V = 110 \text{ V. Also from the figure}$$

$$i_1 = \frac{110}{110} = 1 \text{ A and } i = \frac{110}{11} = 10 \text{ A. So } i_2 = 10 - 1 = 9 \text{ A}$$

Applying Ohm's law for resistance R , $V = iR$

$$\Rightarrow 110 = 9 \times R \Rightarrow R = 12.22 \Omega$$

13. (b) For normal brightness of each bulb see the following circuit.
Current through each bulb = 0.5 A



So the main current $i = 2 \text{ A}$

Also, voltage across the combination = 1.5 V

So voltage across the resistance = 10.5 V

$$\text{Hence for resistance } V = iR \Rightarrow 10.5 = 2 \times R \Rightarrow R = \frac{21}{4} \Omega$$

14. (b) Since the cell gives out a power of 10 W, a current 2 A must flow through the cell towards left.

$$\therefore \text{Power consumed in } 2 \Omega \text{ resistor} = 2^2 \times 2 = 8 \text{ W}$$

$$\text{Total current flowing in } 1 \Omega = 7 \text{ A}$$

$$\therefore \text{Power consumed by } 1 \Omega = 7^2 \times 1 = 49 \text{ W}$$

DPP 7.3

Subjective Type

1. (a) By Ohm's law, current I is given by $I = 6 \text{ V}/6 \Omega = 1 \text{ A}$

$$\text{But, } I = \text{net } A v_d \text{ or } v_d = \frac{i}{neA}$$

On substituting the values,

For n = number of electron/volume = 10^{29} m^{-3}

length of circuit = 10 cm, cross-section = $A = (1 \text{ mm})^2$

$$v_d = \frac{1}{10^{29} \times 16 \times 10^{-19} \times 10^{-6}} = \frac{1}{1.6} \times 10^{-4} \text{ m/s}$$

Therefore, the energy absorbed in the form of KE is given by

$$\begin{aligned} \text{KE} &= \frac{1}{2} m_e v_d^2 \times n A l \\ &= \frac{1}{2} \times 9.1 \times 10^{31} \times \frac{1}{2.56} \times 10^{20} \times 10^8 \times 10^6 \times 10^1 \\ &= 2 \times 10^{-17} \text{ J} \end{aligned}$$

(b) Power loss is given by

$$P = I^2 R = 6 \times 1^2 = 6 \text{ W} = 6 \text{ J/s}$$

$$\text{Since } P = \frac{E}{t}$$

Therefore, $E = P \times t$

$$\text{or } t = \frac{E}{P} = \frac{2 \times 10^{-17}}{6} \approx 10^{-17} \text{ s}$$

Single Correct Answer Type

2. (d) Terminal voltage $V = E - Ir$. Hence the graph between V and I will be a straight line having negative slope and positive intercept.

Thermal power generated in the external circuit

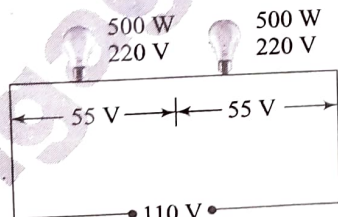
$P = EI - I^2 r$. Hence graph between P and I will be a parabola passing through the origin.

Also at an instant, thermal power generated in the cell = $I^2 r$ and total electrical power generated in the cell = EI . Hence the

fraction $\eta = \frac{I^2 r}{EI} = \left(\frac{r}{E}\right) I$, so $\eta \propto I$. It means the graph between η and I will be a straight line passing through the origin.

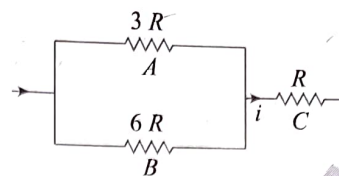
3. (a) Voltage across each bulb $V' = \frac{110}{2} = 55 \text{ V}$ so, power consumed by each bulb will be

$$\begin{aligned} P' &= \left(\frac{55}{220}\right)^2 \times 500 \\ &= \frac{125}{4} \text{ W} \end{aligned}$$



4. (c) Thermal power in $A = P_A = \left(\frac{2i}{3}\right)^2 3R = \frac{4}{3} i^2 R$
- Thermal power in $B = P_B = \left(\frac{i}{3}\right)^2 6R = \frac{2}{3} i^2 R$

Thermal power in $C = P_C = i^2 R$



$$\begin{aligned} \Rightarrow P_A : P_B : P_C \\ = \frac{4}{3} : \frac{2}{3} : 1 = 4 : 2 : 3 \end{aligned}$$

5. (b) $P \propto \frac{1}{R}$ and $R \propto l \Rightarrow P \propto \frac{1}{l}$

$$\Rightarrow \frac{P_1}{P_2} = \frac{l_2}{l_1} \Rightarrow \frac{P_1}{P_2} = \frac{(100-10)}{100} = \frac{90}{100} \Rightarrow P_2 = 1.11 P_1$$

$$\% \text{ change in power} = \frac{P_2 - P_1}{P_1} \times 100 = 11\%$$

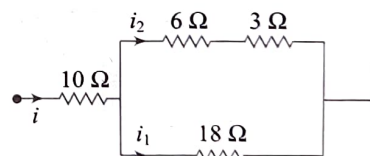
6. (d) Let the resistance of the lamp filament be R . Then $100 = \frac{(220)^2}{R}$

$$\text{When the voltage drops, expected power is } P = \frac{(220 \times 0.9)^2}{R'}$$

Here R' will be less than R , because now the rise in temperature will be less. Therefore P is more than $\frac{(220 \times 0.9)^2}{R} = 81 \text{ W}$.

But it will not be 90% of the earlier value because fall in temperature is small. Hence (d) is correct.

7. (b) The given circuit can be redrawn as follows



$$\frac{i_1}{i_2} = \frac{9}{18} = \frac{1}{2}$$

$$\text{and } i = i_1 + i_2$$

$$\Rightarrow \frac{i}{i_1} = 1 + \frac{i_2}{i_1} = 1 + 2 = 3$$

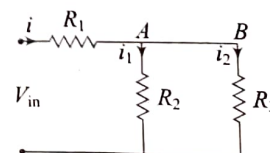
$$\text{From } P = i^2 R \Rightarrow \frac{P_{10\Omega}}{P_{18\Omega}} = \left(\frac{i}{i_1}\right)^2 \times \frac{10}{18} \Rightarrow P_{10\Omega} = 10 \text{ W}$$

8. (c) As the voltage in R_2 and R_3 is the same therefore, according to,

$$H = \frac{V^2}{R} \cdot t, R_2 = R_3$$

Also the energy in all resistance is the same.

$$\therefore i^2 R_1 t = i_1^2 R_2 t$$



Using $i_1 = \frac{R_3}{R_2 + R_3} i = \frac{R_3}{R_3 + R_3} i = \frac{1}{2} i$

Thus $i^2 R_1 t = \frac{i^2}{4} R_2 t$ or, $R_1 = \frac{R_2}{4}$

9. (d) $P_1 = \frac{(220)^2}{R_1}$ and $P_2 = \frac{(220 \times 0.8)^2}{R_2}$

$\frac{P_2}{P_1} = \frac{(220 \times 0.8)^2}{(220)^2} \times \frac{R_1}{R_2} \Rightarrow \frac{P_2}{P_1} = (0.8)^2 \times \frac{R_1}{R_2}$. Here $R_2 < R_1$

(because voltage decreases from 220 V $\rightarrow$ 220 $\times$ 0.8 V
It means heat produced $\rightarrow$ decreases)

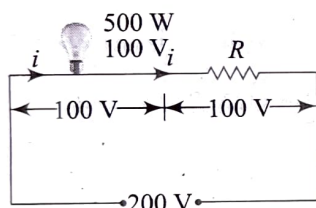
So $\frac{R_1}{R_2} > 1 \Rightarrow P_2 > (0.8)^2 P_1 \Rightarrow P_2 > (0.8)^2 \times 100$ W

Also $\frac{P_2}{P_1} = \frac{(220 \times 0.8) i_2}{220 i_1}$. Since $i_2 < i_1$ (we expect)

So $\frac{P_2}{P_1} < 0.8 \Rightarrow P_2 < (100 \times 0.8)$

Hence the actual power would be between $100 \times (0.8)^2$ W and (100×0.8) W

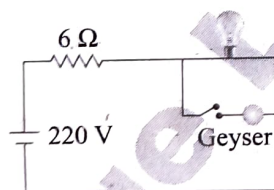
10. (b)



Rated current through the circuit $i = \frac{500}{100} = 5$ A

Potential difference across R, $100 = 5 \times R \Rightarrow R = 20 \Omega$

11. (b) $R_{\text{Bulb}} = \frac{220^2}{100} = 484 \Omega$, $R_{\text{Geyser}} = \frac{220^2}{1000} = 48.4 \Omega$



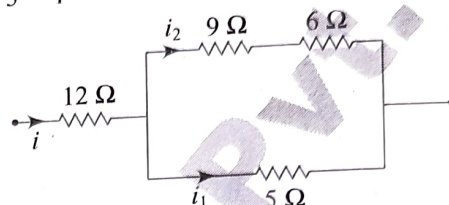
(i) When only bulb is ON, $V_{\text{Bulb}} = \frac{220 \times 484}{490} = 217.4$ V

(ii) When geyser is also switched ON, equivalent resistance of bulb and geyser is $R = \frac{484 \times 48.4}{484 + 48.4} = 44 \Omega$

Voltage across the bulb $V_{\text{Bulb}} = \frac{220 \times 44}{50} = 193.6$ V

Hence the potential drop is $217.4 - 193.6 = 23.8$ V

12. (b) $\frac{i_1}{i_2} = \frac{15}{5} = \frac{3}{1}$



Also $\frac{H}{t} = i^2 R \Rightarrow 45 = (i_1)^2 \times 5$

$\Rightarrow i_1 = 3$ A and from equation (i) $i_2 = 1$ A

So $i = i_1 + i_2 = 4$ A

Hence power developed in 12 Ω resistance,

$P = i^2 R = (4)^2 \times 12 = 192$ W

Multiple Correct Answers Type

13. (b, c)

As the length is doubled, the cross section area of the wire

$R = \rho \frac{L}{A}$ becomes half. Thus the resistance of the wire becomes

four times the previous value. Hence after the wire is elongated the current becomes one-fourth. Electric field is potential difference per unit length and hence becomes half the initial

value. The power delivered to resistance is $P = \frac{V^2}{R}$ and hence becomes one-fourth.

14. (a, b, d)

Total charge = $\int I dt$ = Area under the curve
= 10 C

Average current = $\frac{\int I dt}{\int dt} = 5$ A

Total heat produced = $\int I^2 R dt$

$= \int_0^2 (-5t + 10)^2 \cdot 1 \cdot dt = \frac{200}{3}$ J

Maximum Power = $I^2 R$ when I is maximum current = $100 \times 1 = 100$ W